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Estimation of Permanent Disability in Industrial Accidents

Lead Anemia

Studies in Regard to the Lighting of Post Offices, Made by the United States Public Health Service

Report on Tetraethyl Lead

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ESTIMATION OF PERMANENT DISABILITY IN INDUSTRIAL ACCIDENTS*

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ONE of the perplexing problems that has confronted the medical profession since the advent of workmen's compensation laws is the estimation of permanent disability that may result from an industrial accident. For example, as a result of poor alignment in a Colles' fracture, eight to ten weeks after the injury, deformity, stiffness of the wrist, and weakness of grip of the hand may follow. The responsibility of translating this disability into mathematical percentages has been left to the doctor. The law does not assist him in arriving at a determination for the reason that it stipulates only the amount of compensation to be paid for complete loss of the part, meaning amputation, but implying also loss of use. For example, in New Jersey the Act allows 150 weeks' compensation for complete, or 100 per cent., loss of the hand. No principles are laid down and no criteria are established that may serve as a guide in determining partial disabilities, those that are less than 100 per cent. These form by far the greater number.

It is the common procedure, familiar to those who attend compensation board hearings, for the examining physician to make an inspection of the part involved and, after a few manipulations of the wrist and a request to squeeze the hand, to make a frank guess as to the disability that exists. It is furthermore the accepted opinion that it is impossible actually to determine the percentage of disability. This is the opinion expressed by some of our higher courts. Hence one guess is as good as another. Yet the physician is not altogether guessing when he makes his estimate. One physician

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may be thinking of the effect of the deformity, stiffness, and weakness on the injured man's future earning capacity. One may be considering the effect of the disability on the efficiency in his occupation. Another may be guided by the thought that the deformity may hinder the injured man from easily securing employment. Still others may use the structural condition as a guide in determining the percentage of disability.

It may be readily seen why there is so much discrepancy in the estimates made by several doctors on the same case. It is the rule rather than the exception to find a difference of opinion ranging from 0 to 100 per cent. in individual cases. This is not the result of lack of honesty or sincerity on the part of the examining physicians so much as the result of lack of a common ground on which to meet. In other words, they are not talking the same language. A watchmaker will be completely, or 100 per cent., disabled as the result of the amputation of the last joint of his index finger, yet there are hundreds of vocations that he can follow, occupations for which his training and experience fit him. In an experience of over 40,000 cases examined for the New Jersey Workmen's Compensation Bureau it has been our general experience that a change in vocation was necessary only in disabilities of a very major character, such as amputations, or ankylosis of major joints such as the elbow or knee or shoulder at unfavorable angles. Moreover, in certain cases where we had determined as much as a 75 per cent. loss of the efficiency of the body as a working unit for the routine pursuits of life, the injured man, with courage and perseverance, was still able to follow his former calling, though at a reduced earning capacity.

Again, it was not infrequently the case for the injured employee to earn more after his injury than before, even with a major disability; especially was this the case where our Rehabilitation Commission had an opportunity to train and replace the injured man at a remunerative occupation. It would seem unfair to penalize such a man for ambition and courage by giving him less compensation in view of his increased earnings than another who, because of qualities less noble, is unable to make the grade.

Former Attempts to Estimate Disability

If we trace the compensation law back to its inception in Germany in 1884 we find that little attention, if any, has been paid to a method of appraising the end-results of injury. The attention of the lawmakers at that time was given to devising schedules for absolute structural disabilities such as amputations, ankyloses, loss of sight and hearing, etc. These were copied wholesale from the schedules of private insurance companies as the only available information that could serve as a guide. Our schedules today are but a modification of these old schedules. Little progress was made in this field until 1897 and 1898 when compensation laws were passed in England and France. While England developed the law to its highest perfection in enlarging its scope of usefulness, France played a more important part in the development of schedules of disabilities. The work of such men as Remy; Imbert, Oddo,

and Chavernac (1); Forgue; Jeanbrau; Julliard; Brouardel (2) stands out prominently in this field. To Kauffman and Golebiewski can also be ascribed credit for enlarging the scope of the then existing schedules. Yet none of these men have given us a uniform method of determining permanent disability. They have been satisfied in establishing arbitrary awards for specific injuries based on many factors all of which are essentially variable.

In England recently Llewellyn (3) has made a comprehensive attempt to define the principles of evaluating pensions which might be applied to industrial injuries, but although he has approached the mark when he advises the use of function as the basic standard of evaluation he does not use it alone in making his determinations. For example, after a fracture of the lower third of the femur, he advises taking into consideration shortening, limited motion, and atrophy—essentially anatomic or structural considerations. His entire work is more or less a close imitation of the work of the French writers.

In the United States the International Association of Accident Boards and Commissions has wrestled with the problem of providing uniform permanent disability schedules and of standardizing the value of the different parts of the body. It has not given consideration at all to a uniform method of estimating permanent disability. It recommends that age, occupation, and clinical condition be taken into consideration in making a determination, yet it admits the impracticability of utilizing these factors because of their variability.

The National Industrial Conference Board in its most recent report (4) makes many progressive recommendations concerning the medical aspects of workmen's compensation laws, yet omits to mention the injustice that exists because of the inequitable awards based on doctors' guesses.

Moorhead (5) was the first one to suggest a method of rating permanent disability after fractures. He suggested that three factors be considered: anatomic result, functional result, and cosmetic defect. He ascribes arbitrary values to each factor but does not tell how to measure each factor. Furthermore, the anatomic condition and the cosmetic defect are so variable that they cannot serve as a standard basis for computing disability.

Functional Loss as the Standard for Evaluation of Permanent Disability

In choosing a definite criterion for the evaluation of permanent disabilities, several considerations must be satisfied. The method or principles involved must be practical. The method must be uniform. The method must be accurate; and, finally, it must not be affected by the variations of the disabilities. We have to choose from the following: reduction of earning capacity, loss of efficiency for a specific vocation, structural loss or handicap, cosmetic defect, ability to secure employment, and, finally, functional loss.

Functional loss as a criterion in the evaluation of the permanent disability that may follow industrial accidents meets all the requirements above set forth. Function represents the true measure of ability or disability. What can the man do?

What can the limb do? In what use is the arm deficient? The utilization of this factor as an index to the permanent disability satisfies the fundamental requirements of accuracy, uniformity, and practicability. It is a most stable factor and is the keynote to the vocational and economic ability of the injured. The fundamental principles of appraising disability then recognize the importance of fixed factors as the true criteria in making our estimates. These fixed factors are two: (1) the use of function as the true measure of disability; (2) the application of this measure when the loss of function is permanent or fixed, for, according to our definition, permanent disability is the residual damage or loss of use after all medical and surgical measures have been instituted and sufficient time has elapsed to allow the ordinary consequences of trauma to disappear by natural means.

Definition of Physiologic Function

If we can agree on what constitutes the definition of function in its application to the estimation of permanent disability, we shall be in a fair way to solve our problem. Our criteria must all be objective, not subjective. In this way only can our measurements be accurately determined and malingering prevented. In thinking in terms of function we are prone to think of anatomic function only, such as movement, flexion, extension, rotation, etc. Many workers in this field have erroneously identified movement as synonymous with function. Though intimately related, movement is but one of many factors which enter into the end-results of function, which is the accomplishment of a standard task or test. These factors are: (1) movement of the joints; (2) power of the muscles; and (3) the co-ordination and control from the brain through the peripheral nerves. These are the qualitative components of physiologic function which form the groundwork of an objective which in the upper extremity is reflected in prehension; in the lower extremity, in support and locomotion.

Estimation of Permanent Disability in Upper Extremity

The upper extremity, then, is composed of a chain of four links, consisting of a scapula and clavicle, the humerus, the radius and ulna, culminating in the hand composed of the carpus and fingers, with the attached muscles controlled from the brain by the peripheral nerves. These separate radicles form a composite basis of function that has elevated man to his eminent position in the animal kingdom. As Kant has said, the hand is man's second brain. It is the eye of the blind. It is the tool of tools adapted to every circumstance of life, whether in the pursuit of man's routine duties, such as dressing, eating, etc., or for his vocation, be it mental or physical, light or heavy. The upper extremity resolves itself therefore into its two main components: the tool—the hand and fingers—and the compound lever which gives it its comprehensive scope of usefulness through the movements of the joints of that lever and gives it strength through the muscles contained in that compound lever. The two components are inseparable. One is useless

without the other. Without the freedom of movement of the arm and forearm, the use of the hand and fingers is considerably impaired. Without the use of the hand and fingers, the freedom of movement of the arm and forearm is useless, even though minor tasks may be accomplished. These, however, are negligible and may be properly disregarded.

Measurement of Loss of Function of Arm Radicle

The three physiologic units of function that are to be measured are: motion, strength, and co-ordination.

Motion

Movement of the joints may be measured by arthrometers or goniometers, of which there are many types on the market. Three points should be noted:

1. The instrument should be accurate.

2. Only active motion should be measured.

3. The technic of measuring should be uniform and standardized. The measurement of the range of joint motion will not always be the same when taken from two or more positions. For example, the range of abduction in the hip joint with the hip extended and the body supine will be greater than if the patient lies on his side and attempts to abduct his leg.

The Technic of Mensuration.—The technic of estimating lost motion is as follows. The affected member is compared with the sound one. If both members are affected, compare the range of motion with standard movements such as those determined by Falconer or with other anatomic standards. Only the three major joints are taken into consideration since they form the compound lever for the tool—the hand and fingers. These joints are the shoulder, elbow, and wrist. The ranges of motion in these joints are compared individually with the ranges in the respective joints of the opposite arm. For example, if the right shoulder, as the result of a periarthritis, shows active abduction to 90° and the left shoulder shows 180° for the same motion, there is an obvious loss of 50 per cent. in the abduction movement of the right shoulder. This is considered as a loss of motion for the whole joint. If other motions, such as rotation, flexion, or extension, are involved, they too may be compared with the similar movements on the opposite side, but only one movement is to be used as an index to the motion of the whole joint, and that is the one with maximum loss.

Although from a vocational point of view one joint may be of greater importance than the others, we are unable to determine which is of greater value from a physiologic point of view. Hence an equal value is placed on each joint—shoulder, elbow, and wrist. In the case cited above, the 50 per cent. loss of abduction represents a loss of approximately 17 per cent. of the entire motion in the arm, being 50 per cent. of 33 1/3 per cent. (the shoulder representing an equal third of the entire motion of the arm).

The same method is applied if more than one joint is involved, and the loss in each joint added. For example, a 60 per cent. loss of abduction at the shoulder and a 40 per cent. loss of extension at the wrist would be 60 per cent. of 33 1/3 plus 40 per cent. of

33 1/3, or 33 1/3 per cent., loss of the motion for the entire arm. In the elbow, pronation and supination are not considered as a separate joint function; these motions are ascribed to the elbow joint proper just as the movements of flexion and extension.

Muscular Strength

The next function to be investigated is that of muscular strength. This may be measured by two methods, the ergographic and the dynamometric.

Ergographic Method of Measurement.—In the ergographic method the arm is made to perform a piece of work, such as the rotation of a buggy wheel with the hand and arm, the work done being measured according to a mechanical formula; that work is the product of the force applied over a given distance. The fallacy of this method is that it depends on fatigue as an index to the amount of work performed. Unfortunately, we have no method whereby fatigue can be determined. Lee (6) has definitely shown that no test exists, be it chemical, physiologic, or psychologic, that can demonstrate or measure fatigue.

Dynamometric Method of Measurement.—We have therefore to discard the ergographic method and turn to the dynamometric method. This utilizes as tests for muscular efficiency the force of single maximal contractions of deformable springs and uses these figures as a basis for computing muscular power. That is, the strength is exercised in bending a stiff spring and the degree of bending is observed. The types of instrument most widely used are the grip dynamometer of Collin and the improved form designed by Smedley. When tested out in several hundred cases these were found to give such variable results that they were discarded. Furthermore, they attempted to test only the grip of the hand and not the remaining muscle groups of the arm and forearm. Recourse was had to the spring balance (Fig. 1) graduated in pounds up to 250, with a leather strap or loop attached to one end, which is placed about the muscle group to be tested. The special feature of this test is that it depends on the overcoming by another person of the maximum resistance on the part of the patient. Instead of making a positive effort, the subject in this test confines himself to resisting a pull exerted by some one else. The test has proved successful in the hands of Martin and others in the investigation of strength in its relation to disease as in poliomyelitis and soldier's heart, in relation to physical condition and individual industrial efficiency. For the technic of testing, which is simple and reliable, I must refer you to Martin's papers on the subject (7).

In the upper extremity, the following muscles are tested: the pectorals, anterior deltoid, posterior deltoid, latissimus dorsi, extensors of the forearm, flexors of the forearm, extensors and flexors of the wrist, extensors and flexors of the fingers, and adductors of the thumb. The relative strengths of these muscles have been computed by Martin (8) and are as follows:

Muscle	*Per Cent.*
Pectoral	2.35
Anterior deltoid	2.10
Posterior deltoid	1.40
Latissimus dorsi	1.70
Extensors of the forearm	1.50

Muscle	*Per Cent.*
Flexors of the forearm	2.25
Extensors of the wrist	1.05
Flexors of the wrist	1.35
Extensors of the fingers	0.65
Flexors of the fingers	2.95
Adductor of the thumb	1.30

These figures are valuable in checking up on the test records and in the detection of malingering. As in the test for motion, the opposite side is used as a norm. All the muscle groups as above given are tested and their total amount in pounds compared with the total for the other side. Contrary to accepted ideas, Martin found that the difference in strength between the two upper extremities was so insignificant as to attach no importance to it whatever. Let us suppose that the lost motion of 17 per cent. in the case previously cited was due to a periarthritis of the shoulder, which caused a reading of 285 pounds as the total strength of the affected limb as compared to 320 pounds for the normal arm. This would represent a loss of strength of 35 pounds, or approximately 11 per cent.

Thus far we have two records: (1) loss of motion, 17 per cent.; and (2) loss of strength, 11 per cent. The next record to be obtained is that of co-ordination.

Co-ordination

The efficiency of a muscle or muscle group depends not only on its strength but also on its ability to respond to the excitation of a nerve stimulus which directs it into the proper channel. Of two men with equal strength, one will strike a harder blow because of a greater motor control in his muscles, allowing him to direct it at its target with more efficiency. Co-ordination is intimately connected with dexterity

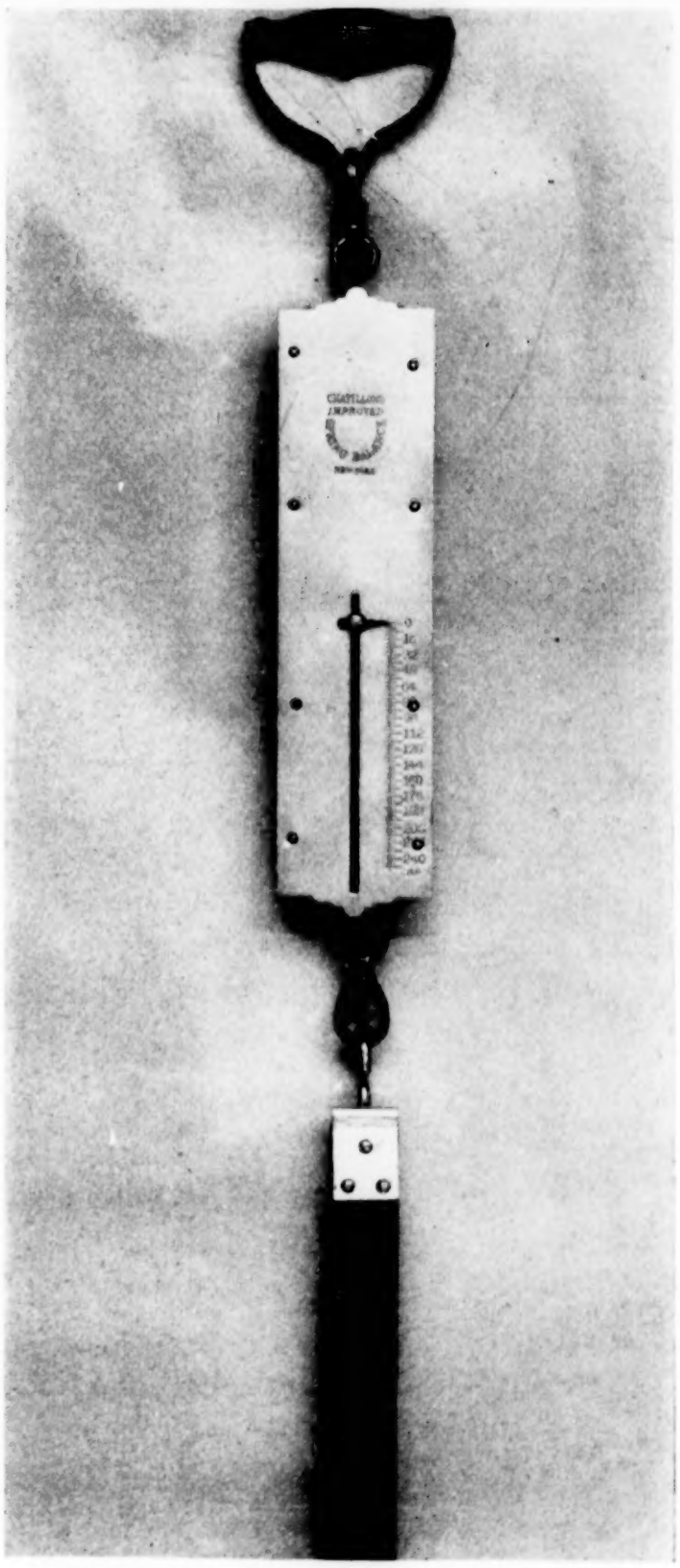

FIG. 1.—The Martin spring balance.

and speed. Tests for these conditions have been devised by psychologists chiefly. Among these are the steadiness tests of Whipple, the aiming and target tests, the tapping tests, and match board tests. A simple test for co-ordination which takes into consideration sensory capacity relies on

the placing of small pegs 1 inch long and one-fourth inch thick into holes of the same diameter. The peg is held between the thumb and index finger and the number of pegs placed

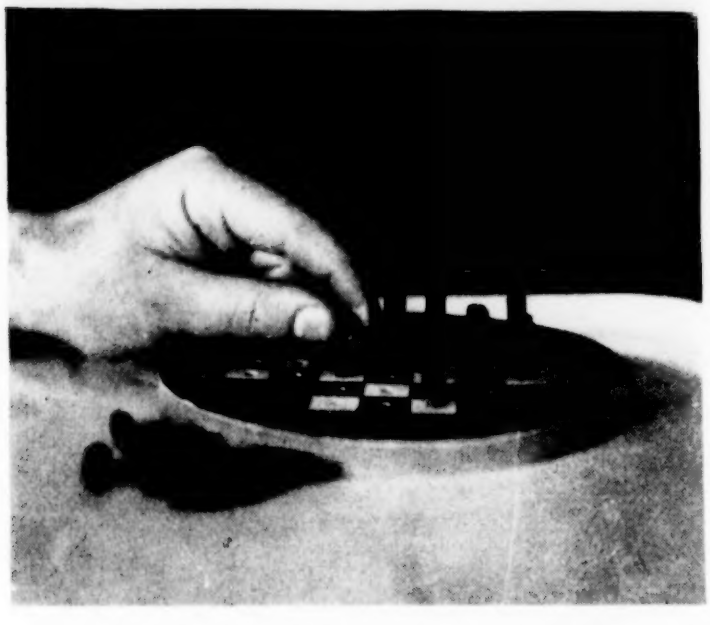

FIG. 2.—Peg hole test for co-ordination.

is compared with the record made by the good hand in the same specified time (Fig. 2). For example, there are 32 pegs. One minute is the allotted time. If the normal hand places 28 pegs in that time and the affected hand 26, the score is read as 26 over 28 or a difference of 7 per cent.

We now have our three factors, as follows:

1. Loss of motion, 17 per cent.
2. Loss of strength, 11 per cent.
3. Loss of co-ordination, 7 per cent.

Just as it is impossible to say which joint—shoulder, elbow, or wrist—is of greatest importance for the routine pursuits of life, for the same reason we must ascribe an equal value to the three factors, motion, strength, and co-ordination. The functional loss of the arm radicle will be equal to the maximum loss of any of its component factors. In the foregoing case this is equal to 17 per cent., represented by the motion factor.

Measurement of Loss of Function of Hand Radicle

The primary function of the hand and fingers is that of prehension. Analyzed into its mechanical analogues we find that it represents a ring, formed by opposing the thumb to the tips of the fingers; a hook, formed by incomplete flexion of the fingers; pliers, by opposing the thumb to the flat surfaces of the fingers; and forceps, by the fine movements between the thumb and the tip of the index finger. Translated into their physiologic equivalents we find three essential units of function which are based on the fundamental factors of motion, strength, and co-ordination. These are: (1) grasping power for small objects between the folds of the fingers, (2) grasping power for large objects between the fingers and the palm, and (3) opposition between the thumb and tips of the fingers. An arbitrary value of 40 per cent. is put on thumb opposition because it can substitute for the small object grasp of the fingers; the latter is given a value of 30 per cent.; and the grasping power for large objects is given 30 per cent.

The same method can be applied to each individual finger, the percentage of disability depending on its ability to grasp small objects, to grasp large objects, and to oppose the thumb. For greater accuracy it is advisable to measure the sum total of motion in all three joints of the affected finger with an arthrometer or protractor and to compare this total with the sum of joint motion of the same finger on the other hand. The difference will be the amount of lost motion. In the absence of tissue loss or sensory dis-

turbance, the loss of motion may be considered as the loss of function for that finger. Where anesthesia occurs recourse must be had to a test for co-ordination. The result is compared to the analogous finger of the other hand. The percentage loss of function of that finger will be equal to the maximum loss as expressed by co-ordination or motion.

Measurement of Loss of Function of Entire Extremity

Having obtained our figures indicating the loss of function of the arm radicle and the hand radicle, how shall we compute the disability to the whole extremity? We know that one radicle is useless without the other. The disability of the entire extremity will depend, therefore, on the maximum disability of either radicle.

For example, if there was an actual loss of 24 per cent. of the function of the arm radicle as determined by measurement and of 40 per cent. of the hand radicle, the whole extremity would be disabled 40 per cent., the maximum of the two disabilities. If the arm radicle was disabled 65 per cent. and the hand radicle 45 per cent., the disability for the entire extremity would be 65 per cent., the greater of the two, and not the addition of the two. This is based on the proposition that the disability of the entire extremity is as great as the disability of its most affected part.

Examples

1. Fracture of head of radius, poor position:

	Percentage Disability
Arm radicle	24
Hand radicle	0
Entire extremity	24

2. Colles' fracture, poor reduction:

	Percentage Disability
Arm radicle	12
Hand radicle	20
Entire extremity	20

3. Compound fracture of elbow with involvement of ulnar nerve:

	Percentage Disability
Arm radicle	18
Hand radicle	40
Entire extremity	40

4. Fracture of metacarpal, poor position, shortening:

	Percentage Disability
Arm radicle	0
Hand radicle	15
Entire extremity	15

Estimation of Permanent Disability in Lower Extremity

In the lower extremity, motion in the hip, knee, and ankle joints, strength, and co-ordination as exemplified in gait are similarly measured. The muscle groups that are tested for strength and the totals of which are added are plantar and dorsal flexion, inversion and eversion of the foot, adduction and abduction of the hip, extension and flexion of the hip, and extension and flexion of the knee. Martin has likewise computed the relative strength among these muscle groups. This computation forms a valuable guide as to the correctness of the record and as to the detection of malingering. The findings of these three factors—motion, strength, and co-ordination—correspond to the findings in the arm radicle of the upper extremity. Weight bearing has the same relation and importance in the lower extremity that prehension has in the upper extremity. Weight bear-

ing is tested by putting the patient on his back; the leg is held with the knee stiff; the loop of the spring balance passes around the heel of the foot to be tested; the foot and knee are steadied; and the operator stands at the head of the patient and exerts a gradual tension in a horizontal plane until the knee gives or bends. The reading is then taken. The disability of the entire lower extremity will depend on the maximum disability as encountered in the resultant of motion, strength, and co-ordination of the lower extremity, and of the weight bearing reading.

These factors give the picture of function of the lower extremity. On these factors, the lower extremity depends for support and locomotion, whether it be on the level, up or down, with or without a load. Amar (9) has very ingeniously measured weight bearing by kymographic methods, but because of the elaborate technic and apparatus necessary this procedure does not lend itself for practical purposes.

It is impossible to cover the entire human body in the short time allotted. I hope to have the entire field covered for publication at an early date. The work is still in its infancy and will bear more thought and study. It is my belief, however, that the application of the foregoing principles will do much to assist in the equitable adjudication of compensation claims. As for the medical examiner, he stands as an arbitrator between the employer and the employee. The former wants to see his just debts paid and seeks protection from malingering. The latter looks for an honest, accurate appraisal of his disability. In case of doubt, the weight should be thrown to the injured man.

Summary

1. The estimation of permanent disability depends not on the expression of a personal opinion but on the measurement of functional disability.

2. The estimation and measurement must be made when the clinical condition may be said to be fixed, unchangeable, and permanent.

3. The upper extremity is divided into two component parts, the arm radicle and the hand radicle.

4. Measurement of the loss of function of the arm radicle consists in measuring the loss of motion, muscular strength, and co-ordination.

5. Measurement of the loss of function of the hand radicle consists in measuring the ability to grasp small objects, to grasp large objects, and to oppose the tips of the fingers.

6. The same method as used in measurement of the loss of function of the hand radicle may be used for finger estimating.

7. The disability of the entire extremity will depend on the maximum disability of either radicle.

8. The disability of the entire lower extremity will depend on the maximum disability as encountered in the resultant of motion, strength, and co-ordination of the lower extremity, and of the weight bearing reading.

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LEAD ANEMIA*

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THE blood picture in lead poisoning has a peculiar significance from the standpoint of diagnosis; for, curiously enough, the diagnosis of this disease in its early stages is still uncertain despite the fact that poisoning by lead is foremost among the industrial diseases. In its acute or advanced chronic stages, the characteristic pallor, the lead line on the gums, the colic, nephritis, and wrist drop have become familiar even to the layman. In the borderline cases, however, there appears to be no end of difficulty in establishing the diagnosis. Cases of lead colic are still being operated on for appendicitis. And from the standpoint of compensation, the absence of anything which can be regarded as pathognomonic of this disease is constantly leading to considerable confusion, and frequently to serious injustice to the worker.

Stippling of the red blood cells, or basophilic degeneration, was at one time regarded as pathognomonic of lead poisoning. Unquestionably it occurs in lead poisoning more frequently than in any other of the secondary anemias. But the fact that it also occurs in the other anemias and in leukemia, as well as in the cells invaded by the parasite of tertian malaria, and in some of the infectious diseases of childhood, including pneumonia, has resulted in much uncertainty as to its precise significance in lead poisoning. This has been still further increased by the fact that an occasional stippled cell has been reported from time to time in normal blood. The result has been an unending discussion as to the frequency of occurrence of stippling in lead poisoning, as well as to the number of stippled cells which must be found per field before the case can be regarded as one of lead poisoning. The Sickness Insurance Office at Leipzig, Germany, has taken the extreme position that the presence of stippled cells in the blood is the fundamental basis for compensation. And it is alleged that the use of this standard not only has made it possible to give assistance to persons in the early stages of the disease—before irreparable damage has been done—but also has been of value in eliminating many cases which were erroneously diagnosed as lead poisoning.

The Bureau of Industrial Hygiene of the New York State Department of Labor, as part of its more comprehensive lead investigation, has been making a study of the health status of some 400 odd lead workers in the state of New York. Examinations were made in the various plants, so that only those men were included who were up and about and at work. This series

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does not include, therefore, any cases of incapacity, or any cases of acute lead poisoning. In each case, a careful history was taken, and a complete physical examination and laboratory analyses of the blood, urine, swabs from the nose, air samples, etc., were made. The men thus examined represented twenty-three plants in fifteen lead industries. They were exposed to lead in the following forms:

Lead fumes.
Red lead paste.
Red lead and litharge dusts.
Dry and wet paints.
Dry and wet chrome colors.
Dry and wet pottery glaze.
Pig lead and metallic lead dust.
White lead as such.

Blood Findings in New York Investigation

The blood findings only are the subject of the present preliminary report. The further correlations between these findings and all of the other factors will be reserved for the bulletin on lead which is to be published shortly by the Bureau of Industrial Hygiene of the New York State Department of Labor.

The blood was examined in 381 cases. This examination was not confined to a search for stippling, but included in addition a red blood cell count, a white blood cell count; a hemoglobin determination, using the Sahli method; a differential count; and a careful examination of the morphology of the cells in each blood smear. The thin smear method was used. The smears were fixed in methyl alcohol and then stained by a special eosin-methylene blue stain which proved to be very satisfactory.

Normal Controls

Because of the great difference of opinion with regard to the frequency of occurrence of stippling in normal blood, and the difficulty of coming to any satisfactory conclusion on this point from the scanty evidence available, blood smears were made on 250 normal individuals. One hundred and fifty of these were medical students at the time of their final examinations; the other 100 were laborers of various sorts, seventy of whom were applying for compensation for minor injuries. These last were obtained by the courtesy of Dr. Raphael Lewy at his clinic. The technic was exactly the same as that used for the lead smears. This control series proved to be very interesting, in that one stippled cell was found in the last slide that was examined. It would seem from this that stippling is of sufficiently rare occurrence in normal blood as to be practically negligible—0.4 per cent. Four slides showed slight pallor of the red cells, but otherwise there was nothing abnormal to be found.

Blood Changes in Lead Workers

Of the 381 lead workers examined, 238, or 62 per cent., showed one or more of the following blood changes, and in the following order of frequency as shown by Figure 1:

	Per Cent.
Anemic red cells	71
Anisocytosis	44
Polychromatophilia	40
Stippling	39
Poikilocytosis	23
Nucleated red cells	8
Eosin myelocytes	2
Other abnormal cells	1

It is interesting to note that stippling ranks only fourth in importance among the blood changes found, and that it was present in only 39 per cent. of the cases showing blood changes, or 24

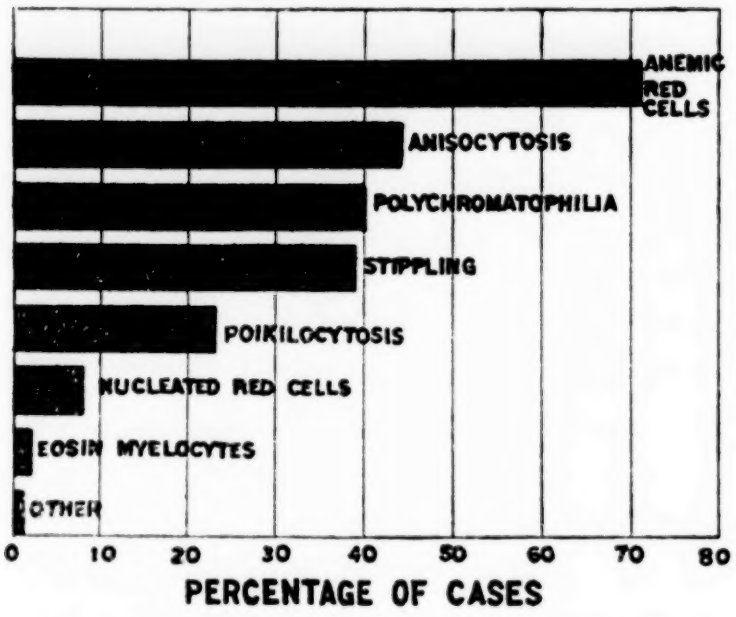

FIG. 1.—Showing the relative prevalence of the various types of blood changes found in 238 cases.

per cent. of the total number of cases examined. Pallor of the red cells, anisocytosis (or change in size), and polychromatophilia were all more prevalent than stippling, and in the order mentioned. Poikilocytosis (or change in the shape of the red cells), nucleated red cells (or normoblasts), and eosin myelocytes occurred in a considerable number of cases as shown in Figure 1. All of these changes were found both alone and in various combinations—both with and without the presence of stippled cells. In nineteen cases, or slightly less than 8 per cent. of those showing blood changes, stippling was found unaccompanied by any other blood changes. It will also be noted that polychromatophilia and stippling were about equally prevalent among the blood changes, though they were by no means always found to occur in the same cases. This is of special interest because of the fact that they are most closely allied morphologically of all the blood changes. They are both different manifestations of basophilic degeneration of the red cells. A diffuse homogeneous basophil staining of the cytoplasm of the red cell is known as polychromatophilia. Stippling is characterized by the presence of basophil granules of various sizes scattered throughout the otherwise normal cytoplasm of the red cell.

DIFFERENTIATION OF PRIMARY AND SECONDARY AND LEAD ANEMIAS

It would seem from the foregoing that perhaps too much importance has been given in the past to stippling as such, and too little emphasis been placed on the blood picture as a whole. This blood picture does not give one the impression of stippling above all else, but presents rather the picture of an anemia. And the question arises: What is it that differentiates this anemia (which we call *lead anemia* for convenience) from all the other anemias? In order to arrive at a proper evaluation, it might be well to pause here a moment, and run over rapidly the essential points of differentiation between the primary and secondary anemias, and see wherein lead anemia differs from both, as it apparently does in some respects.

It will be remembered that the color index is the line of demarcation between the primary and secondary anemias. In pernicious anemia, the color index is above 1, which means that the amount of hemoglobin per red cell is relatively high, whereas in the secondary anemias the color index is below 1, indicating a reduction in the hemoglobin which is in excess of the

reduction in the number of red cells. All of the blood changes indicated above as having been found in the blood smears taken from the lead workers have also been found in both of these anemias. In the symptomatic secondary anemias, the more severe the anemia, the lower the red cell count, the lower the color index, and the greater the frequency of occurrence of such other blood changes as stippling, anisocytosis, poikilocytosis, polychromatophilia, nucleated red cells, etc. Eosin myelocytes occur very rarely in this disease, and only in the most severe cases. The presence of all of these abnormal red cells in the blood is a manifestation either of cell degeneration and cell destruction or of inadequate red cell production, accompanied by an attempt on the part of the blood forming organs to make up the deficiency in a hurry, with the result that immature and imperfectly formed cells are thrown into the circulation. In pernicious anemia, all of these abnormal cells, including stippled cells, are found in greater numbers than in secondary anemia, and, as is well known, there are to be found in addition large numbers of megalocytes and megaloblasts. The megaloblastic character of the blood smear in pernicious anemia is a very important point from the standpoint of diagnosis—quite as much so as stippling in lead poisoning—and yet the diagnosis is never made on the basis of this one finding alone. Indeed, megalocytes and megaloblasts cannot always be demonstrated in each blood smear even after careful search, just as stippling cannot always be demonstrated, since they both appear in the circulation rather intermittently. A relatively low leukocyte count and a relative lymphocytosis at the expense of the polymorphonuclear leukocytes in pernicious anemia are the further points of differentiation between it and the severe secondary anemias. Myelocytes are more characteristic of the leukemias than of either of the groups of anemias, but are found more often in pernicious anemia than in secondary anemia.

The stippling in lead anemia is somewhat different in its origin from that which is found in pernicious anemia. In the former condition, the stippling is thought to be due to a degeneration of the protoplasm of the red cells. Key has shown that the stippled cells here are young red cells in which degenerative changes have occurred as a result of the toxic action of the lead. The granules are probably aggregations of part of the basophilic substance into small discrete masses. These changes occur in the peripheral circulation. There are no stippled cells found in the bone marrow in lead poisoning. In pernicious anemia and leukemia, Wood points out that the stippling is due rather to the breaking up of the nucleus of the red cell. This process is known as karyorrhexis, and occurs in the bone marrow, as well as in the nucleated cells of the peripheral circulation. In lead anemia, the stippling usually occurs in otherwise normal red cells—*i.e.*, in non-nucleated red cells—and nucleated red cells may be entirely absent from the circulation.

As is well known, there is nothing which can be pointed to as pathognomonic of any of the various anemias. In fact, it is very difficult, as Wood points out, to draw any hard and fast

line between them. "The distinctions which are made between the various types are based upon an average morphology, so to speak, and each group may have clustered about it a large number of types which differ only slightly from each other and gradually bridge over the sharp distinctions between the groups. . . . . Between the two ends of the series the difference in the blood morphology is so striking that there is no possibility of confusion, but to distinguish between the forms lying adjacent to one another is at times very difficult, if not impossible, merely from examination of the blood alone." In each case, therefore, the *whole blood picture* is examined very carefully before the diagnosis is attempted, and usually several smears are examined rather than one.

In the case of lead anemia, therefore, where on the whole the cell changes are quite similar to those found in the other anemias (though perhaps quantitatively differently distributed), we should regard the blood picture *as a whole* rather than stress any one element in it, no matter how important that one element may be. It would seem quite as improper to diagnose a case of lead anemia by the presence or absence of stippled cells as to diagnose a case of pernicious anemia by the presence or absence of megaloblasts alone, without regard to the other blood elements. And in the case of all the anemias, a diagnosis of the condition on the basis of the blood picture alone may be impossible in certain cases without reference to the clinical findings. This fact must also be taken into consideration in the case of lead anemia.

Characteristics of Lead Anemia

What, then, are the distinguishing characteristics of lead anemia as brought out by the present study? What is it that makes it the blood disease entity which it seems to be? In general, it might be said that lead is a toxic substance causing increased destruction of the red blood cells both in the peripheral circulation and in the bone marrow. Charteris has described a preliminary hyperplasia of bone marrow followed later by a gelatinous degeneration. The weight of evidence seems to indicate that these changes occur, however, only in advanced stages, the destruction usually occurring only in the peripheral circulation. This destruction in the peripheral circulation is thought to be enhanced by the fact that leaded red blood cells show increased fragility, and the experiments of Broun on normal cells would lead one to believe that this increased fragility renders them more subject to trauma than normal cells in the course of circulation. This conclusion is of interest in view of the following findings with reference to the relation of the red cell count to the hemoglobin.

Red Cell Count and Hemoglobin

The red blood cell count, though as low as 2,800,000 in a few instances, was on the whole not very much reduced. The average count found was 4,000,000, which is 80 per cent. of the 5,000,000 regarded as normal for the adult male. Previous investigations made by this Bureau of 110 men working in steam laundries, and of fifty men working in a plaster factory—all sturdy laborers of the same general class from which most lead

workers are recruited—demonstrated the fact that men of this type have a red blood cell count well up to and frequently above 5,000,000, and a correspondingly high hemoglobin.

The average hemoglobin in this series is 79 per cent., giving a color index of very little less than 1. This is important. It will be seen by reference to Table 1 what the distribution of cases has been with reference to hemoglobin. It was noted that 31 per cent. of the cases had a hemoglobin percentage of over 80. While in individual cases the red cell count and the hemoglobin have been quite low and the color index well under 1, the average picture is one of a really rather mild—in many cases, very mild—secondary anemia. One can readily see, therefore, how, in a given case, an examination of the red cell count and the hemoglobin might reveal changes in these two factors which are so slight as to cause no suspicion that more significant blood changes have occurred. For in the ordinary secondary anemia, so slight a reduction in the red cell count and in the hemoglobin would indicate an anemia so mild as to suggest very little else in the blood picture. But the significant thing here, in differentiating lead anemia from the ordinary secondary anemia, is this: that accompanying an anemia which from the red cell count and from the hemoglobin appears to be very slight there may be such serious blood changes as stippling, polychromatophilia, the presence of nucleated red cells in considerable numbers, anisocytosis, poikilocytosis, and even eosin myeloblasts and Türck's irritation cells—all of these pointing to a blood condition out of all proportion to what one would be led to expect from the red cell count and the hemoglobin. (See Fig. 2.) This emphasizes again the extreme importance of looking at the whole blood picture in the diagnosis of lead anemia. As has been shown,

TABLE 1.—SHOWING AN ANALYSIS OF HEMOGLOBIN DISTRIBUTION AND THE RELATION BETWEEN HEMOGLOBIN AND PALLOR IN 378 CASES

HEMOGLOBIN PER CENT.	NO. SHOWING PALLOR	NO. SHOWING NO PALLOR	TOTAL
45–50	1	1	2
51–55	3	1	4
56–60	4	5	9
61–65	4	5	9
66–70	12	36	48
71–75	19	43	62
76–80	17	108	125
81–85	11	39	50
86–90	6	46	52
91–100	2	15	17
Total...	79	299	378

even stippling may be absent and the other blood elements above mentioned be present in significant numbers.

It will be seen by reference to Figure 2 that nucleated red blood cells, or normoblasts, were found associated with hemoglobin percentages ranging from 45 to 90. Stippling has been found with hemoglobin ranging from 55 to 97.5 per cent. Such other changes as poikilocytosis, anisocytosis, polychromatophilia, etc., are to be found associated with hemoglobin ranging from 45 to 100. Eosin myelocytes were found with hemoglobin ranging from 78 to 90. The significant fact to be borne in mind is that these blood changes may

be associated with a relatively high hemoglobin content of the blood, and should always be looked for, no matter how mild the anemia may appear to be superficially. This is regarded as one of the most important

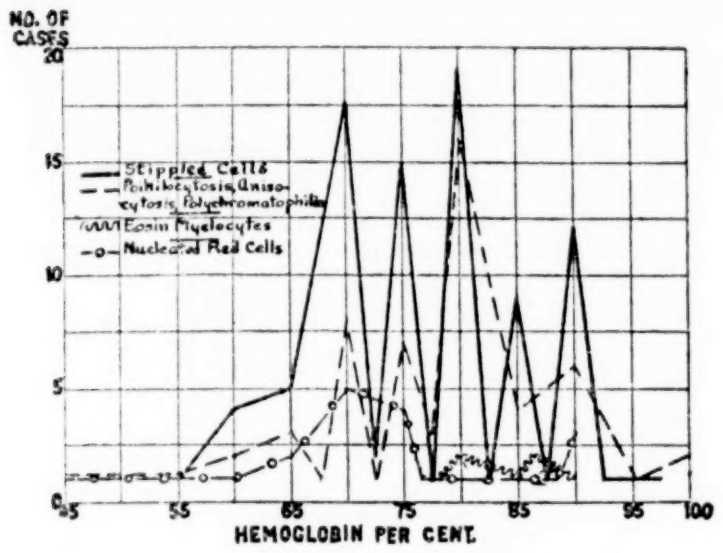

FIG. 2.—Showing the relation of the hemoglobin percentage to the occurrence of stippled cells; poikilocytosis, anisocytosis, and polychromatophilia; eosin myelocytes; and nucleated red cells.

points in the differential diagnosis of lead anemia as brought out by the present investigation.

Pallor

The ashen pallor in lead poisoning differs very markedly from the greenish pallor of secondary anemia and the lemon yellow pallor of pernicious anemia. It differs not merely in appearance but in the curious fact that it appears to have no definite relation to the reduction either in hemoglobin or in the red cell count. This relationship is rather striking in the other anemias. In lead poisoning, a marked pallor both of the face and of the lips has been regarded as very characteristic of the disease, but authorities agree that marked intoxication may occur without it, and, *vice versa*, that it may be very marked in very mild cases. Koelsch believes that it is probably due to the action of lead on the skin capillaries—a vasoconstriction due to faulty nerve mechanism. Pallor is really a clinical manifestation of the disease, and as such does not properly belong in the present discussion. Pallor and hemoglobin are so closely associated in one's mind, however, that it seems desirable to say a word here concerning the present findings. It will be seen in Table 1 what has been found to be the prevalence of pallor in the present series, and in general what has been found to be its relation to the hemoglobin content of the blood. It will be noted that the present findings are entirely in accord with what was to be expected. Indeed, some of the most marked cases of pallor have been found associated with hemoglobin percentages of 90 to 100. And on the other hand, cases of relatively low hemoglobin, often combined with moderate intoxication, have not always been associated with any great degree of pallor. This is of supreme importance from the standpoint of the industrial physician who so often depends on pallor alone as a guide to whether a particular worker should be transferred to another part of the plant for purposes of recuperation.

White Cell and Mononuclear Counts

Lead anemia appears to be characterized further by a slight relative lymphocytosis at the expense of the polymorphonuclear leukocytes, and is associated with no increase in the white cell count. In this respect it appears to differ from acute cases of lead poisoning. It tends to resemble pernicious anemia to a certain extent although in the latter the white cell count is sometimes reduced. The

average lymphocyte count for the series is 39 per cent. Sixty-two per cent. of the cases showing blood changes were found to have a lymphocyte count of over 35 per cent.

The large mononuclear count was

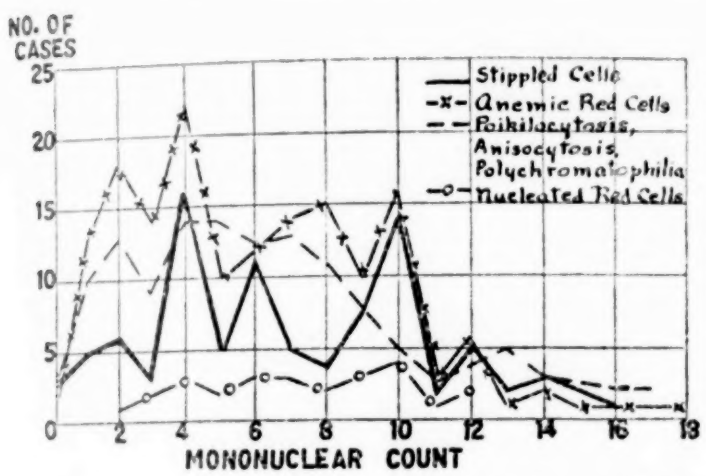

FIG. 3.—Showing the relation of the mononuclear count to the occurrence of stippled cells; anemic red cells; poikilocytosis, anisocytosis, and polychromatophilia; and nucleated red cells.

also above the normal of 1 to 2 per cent., the average for the series being 6 per cent. Thirty per cent. of those having blood changes had a mononuclear count of over 6. Figure 3 shows a correlation between the various blood changes and the mononuclear count. It will be observed that while all of the blood changes may occur with any mononuclear count of from 0 to 18 per cent., they are associated in greater numbers with counts varying from 4 to 10 per cent.

CONCLUSIONS

1. The 381 cases herein described include no cases of acute lead poisoning. The blood changes are those which have been found to occur in lead workers who do not consider that they are ill.

2. Lead anemia is a blood disease entity having the following diagnostic features:

(*a*) The red blood cell count and hemoglobin are only slightly reduced in all but severe cases, giving the appearance of a very low grade secondary anemia.

(*b*) The color index is in the average case only a little less than 1, although it gets lower as the red cell count and the hemoglobin are reduced.

(*c*) This apparently low grade anemia is associated with changes in the morphology of the red cells which are out of all proportion to what would be found in the ordinary case of secondary anemia of the same severity. Of these blood changes, stippling ranks fourth in frequency, having been demonstrated in 39 per cent. of the cases showing blood changes, and in 24 per cent. of the total cases.

(*d*) Stippling of the red cells, though more prevalent in this anemia than in the other secondary anemias, is only one of a number of pathologic blood changes and must be considered in conjunction with the rest of the blood picture, if its true significance is to be appreciated.

(*e*) Stippling and polychromatophilia occur in approximately the same percentage of cases, though they frequently occur one without the other.

(*f*) The white cell count is normal, but there is a slight relative lymphocytosis at the expense of the polymorphonuclear leukocytes. The average lymphocyte count was found to be 39 per cent.

(*g*) The mononuclear cell count was found to be somewhat increased, the average for the series being 6 per cent.

(*h*) An ashen pallor characteristic of lead poisoning appears to have no definite relation to the red cell count, the hemoglobin content of the blood, or the severity of the intoxication, but

appears to be due to some neuro-vascular capillary disturbance.

3. The diagnosis of lead anemia must depend on a careful examination of the *whole* blood picture. It is desirable that here, as in other anemias, more than one slide be examined since many of these cells, particularly stippled cells, appear in the circulation only intermittently.

It is hoped that the recognition of lead anemia as an entity, of which stippling is only one of many factors, will materially assist in increasing the value of the blood findings for the diagnosis of lead poisoning. Whether lead anemia without clinical manifestations and lead poisoning, from the compensation standpoint, should be regarded as identical is a question which is outside the province of the present discussion. But surely in those numerous cases which are so troublesome to the compensation courts, where the symptoms complained of by the worker are so vague as to bear none of the definite earmarks of lead poisoning, the blood picture should be of material assistance. For example, if a worker is incapacitated from work because of headaches, dizziness, or loss of appetite—all of which might be due to a thousand and one causes other than exposure to lead—the finding of a typical lead anemia—*either with or without stippling*—should clinch the diagnosis. Undoubtedly there will be cases where even with the entire blood picture at hand the diagnosis will still remain in doubt. On the whole, however, it is to be expected that the whole blood picture will give considerably more valuable information than would the mere fact of the presence or absence of stippled cells.

I wish to express my appreciation to Helen Rivkin, M.A., of the Department of Bio-Chemistry, Columbia University, and to Dr. B. Choun, Pathologist, Nursery and Child's Hospital, for the care with which they examined the blood smears.

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STUDIES IN REGARD TO THE LIGHTING OF POST OFFICES, MADE BY THE UNITED STATES PUBLIC HEALTH SERVICE*

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HISTORY OF THE STUDY

THE study of the lighting of post offices was undertaken by the Office of Industrial Hygiene and Sanitation of the United States Public Health Service at the request of the Postmaster General, in order to determine whether the illumination prevailing in the offices at the time of the study was sufficient and of the most desirable character.

After a preliminary survey in 1920 of a number of post offices in the East, an intensive study of two post offices in the city of New York—the old City Hall post office and the relatively new general post office—was made during the winter of 1921 to 1922 (1). A thorough investigation was made of the lighting prevailing in these offices at that time, of the processes involved in the work, and of the condition of the eyes of the employees. Of the 3,695 men and women employed regularly at that time in these offices, 2,449 were given eye examinations—709 in the City Hall post office, and 1,740 in the general post office.

Further studies of the effect of the degree of illumination on production were made during the year 1923 in the New York City Hall post office, and similar studies are being carried on at the present time in the main post office in Chicago, Ill.

FACTORS AFFECTING EYESIGHT

Degree of Illumination

It was found that in the City Hall post office the work was practically all performed under artificial illumination, whereas in the general post office only about 60 per cent. of it was done under artificial illumination, the rest being done under good daylight illumination, of an average value of 12 foot candles or more.

In both post offices the average artificial illumination was about 3.5 foot candles,[1] although in the general post office it was slightly higher than in the City Hall office. Apparently as the direct result of this difference in the lighting of the two post offices,

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[1] A foot candle is the illumination on a surface at a distance of 1 foot from a standard candle.

TABLE 1.—PERCENTAGE OF THE 2,449 EMPLOYEES EXAMINED IN THE NEW YORK CITY HALL AND GENERAL POST OFFICES, WITH CERTAIN EYE CONDITIONS

POST OFFICE	NORMAL VISION IN BOTH EYES WITH NO DEFECTS	NORMAL VISION IN BOTH EYES WITH DEFECTS	NORMAL VISION IN ONE EYE ONLY	NORMAL VISION IN ONE OR BOTH EYES	DEFECTIVE VISION IN BOTH EYES	REFRACTIVE ERRORS	INFLAMMATORY CONDITIONS	MUSCULAR UNBALANCE	ASTHENOPIA
City Hall	10.3	29.5	17.8	57.5	42.5	76.6	20.9	33.4	16.5
General	19.8	29.9	17.6	67.4	32.6	72.5	11.9	22.4	5.7

the condition of the eyes and eyesight of the employees in the former was better than in the latter. This is shown in Table 1, where it will be seen that the percentage of employees having normal vision is, in general, greater in the general than in the City Hall post office, and that the percentage of those with eye defects is less. By normal vision is meant a visual acuity of 20/20 or better.

The inevitable conclusion from these results seems to be that the low illumination prevailing in the City Hall post office had had an injurious effect on the eyes of those working under it.

Age and Character of Work

Another interesting fact brought out by the eye examinations was connected with the change in the acuity of the eye with age. It was found that the percentage of employees having normal vision in one or both eyes decreased slowly from about 20 to 45 years of age, and more rapidly from 45 years on. This is shown by the graph in Figure 1.

These results were confirmed by a study (2) made recently by the Statistical Office of the United States Public Health Service of the vision of

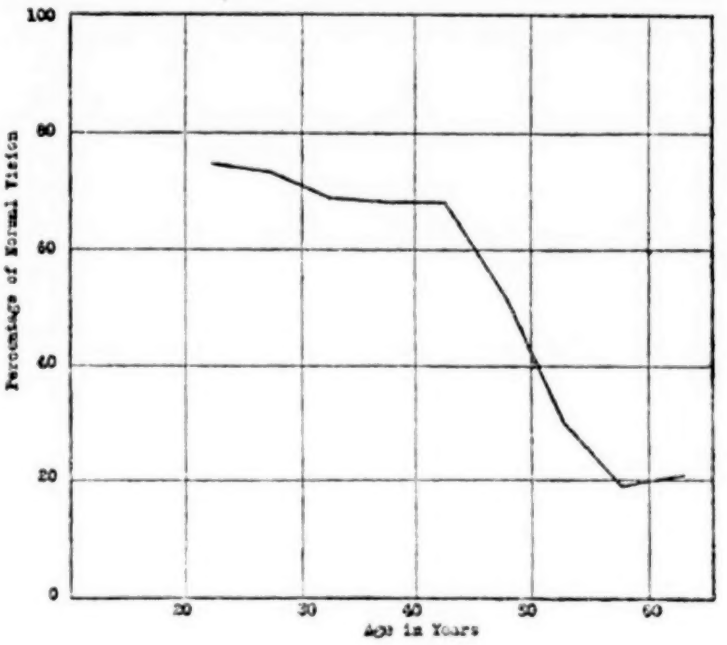

FIG. 1.—Percentage of normal vision in one eye or in both eyes for 2,449 employees of the New York City Hall and general post offices, by ten-year age groups.

4,862 native white school boys and 6,479 male white industrial workers in the United States. The results of this study are shown in Figure 2.

Figure 2 also presents another very interesting fact, not brought out by the post office investigations (since there were no employees under 18 years of age), *viz.*, that the percentage of persons having normal visual acuity in one eye or both eyes, or in both eyes, increases from about 5 years of age (the youngest age examined) to about 18 years, when it reaches a maximum, after which it decreases. These re-

sults would seem to indicate that white males in the United States reach the greatest acuity of vision at about 18 years of age.

The fact that there appeared to be the least amount of change in visual acuity from 25 to 45 years of age was utilized to make a study of the effect on the eyes of the character of work performed in the New York post offices. All the white males whose eyes had been examined were divided into two groups, *viz.*, those under and those over 45 years of age; each group was again divided into groups according to the character of the work performed, arranged in order from the least to the greatest eye work, *viz.*, into laborers, facers, parcel post separators, newspaper separators, clerks, and letter separators.

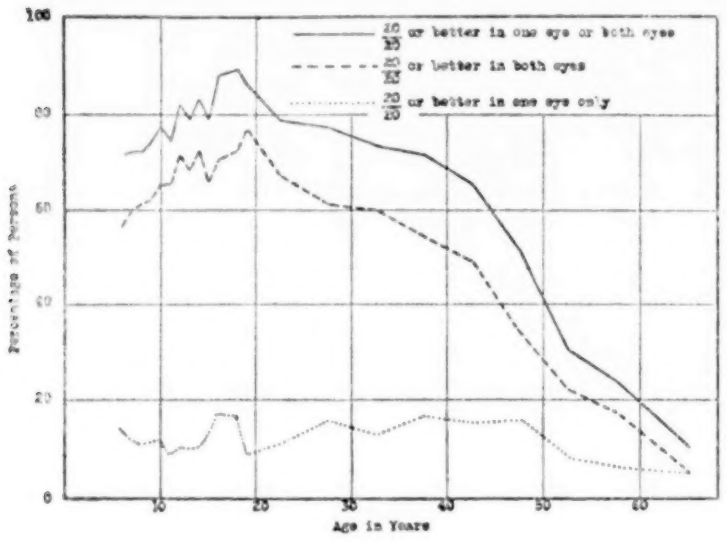

FIG. 2.—Percentage of persons of each age group with the specified vision as determined by the Snellen test, for 4,862 native white school boys and 6,479 male white industrial workers in the United States.

The results of this classification are shown in Table 2. It will be seen that for both groups those doing the most intensive eye work have in general the poorest vision and the greatest

TABLE 2.—PERCENTAGE OF WHITE MALES UNDER AND OVER 45 YEARS OF AGE, ACCORDING TO EYE CONDITIONS, IN BOTH POST OFFICES, BY OCCUPATIONS[1]

	UNDER 45 YEARS OF AGE					OVER 45 YEARS OF AGE				
	Laborers (134)	Others[2] (105)	Newspaper Separators (186)	Clerks (533)	Letter Separators (528)	Laborers (52)	Others[2] (66)	Newspaper Separators (30)	Clerks (205)	Letter Separators (81)
	%	%	%	%	%	%	%	%	%	%
Normal in one eye or both eyes	81.4	70.5	67.7	73.0	65.5	38.5	31.8	30.0	37.1	29.6
Refractive errors	56.0	68.6	72.0	70.2	74.6	88.5	86.6	93.3	91.4	90.1
Inflammatory conditions	12.7	13.4	17.7	17.6	20.9	13.5	9.0	20.0	21.2	27.2
Muscular unbalance	16.4	19.0	30.4	23.9	30.7	13.5	22.4	13.3	24.7	18.5
Asthenopia	1.5	2.9	12.2	8.2	7.9	1.9	0.0	3.3	3.5	18.5

[1] Fifteen of the white males examined were not classified as to occupation, because they were substitutes.

[2] Others include facers, parcel post separators, and executives.

number of eye defects. This is more marked for the group under 45 years of age, but is true in a lesser degree for the group over 45 years of age.

Tests Made at New York City Hall Post Office

Card Sorting Tests

Since the comparative study of the two post offices indicated that the ocular conditions were better in the general post office, where a higher illumination prevailed, it seemed reasonable to suppose that a higher illumination was desirable than that prevailing in the City Hall post office; the question arose, therefore, as to what the nature and degree of this illumination ought to be. This question was approached from two points of view: first, from a consideration of recommendations made for similar work in recent codes of lighting, such as the American Standard Code of Lighting, prepared under the direction of the Illuminating Engineering Society, and the various state codes; and second, by making actual tests as to the influence of the degree of illumination on the speed with which letter sorting (the most important work in the post office) could be performed, under the assumption that the illumination under which sorting could be performed most rapidly would be that which would be best for the eyes.

From these two sources the conclusion was arrived at that the illumination on the working plane should be at least 10 foot candles when the lighting units were first installed. This would allow for a deterioration of 20 per cent., so that under ordinary conditions the illumination would not fall below 8 foot candles.

The tests for speed of sorting were made by determining the speed and accuracy with which a worker could sort 1,000 white cards addressed in black typewriting under successive illuminations of 2.8, 3.6, 8, and 14 foot candles. Twelve subjects were employed in the tests, and were divided into three groups according to their visual acuity: group A, having acuity of 20/20 in both eyes, with no defects or diseases; group B, having acuity of 20/20 partly to 20/30, with no abnormalities except errors of refraction; and group C, having acuity of 20/30 partly to 20/40, with no abnormalities except errors of refraction (1). The results of the tests are shown in Table 3. It will be seen from the table that on an average the greatest speed of sorting was reached at about 8 foot candles. It will also be noted, however, that while the better vision groups, A and B, reached their maximum speed at about 8 foot candles, the poorest vision group, C, only reached its greatest speed under 14 foot candles.

Consideration of the requirements of post office work led to the recommendation that the lighting units should be completely enclosed, made of opal glass and so large that the brightness of any point of their surface would not be greater than 2.5 candles per square inch. A brightness of 2.5 candles was taken as the maximum allowable, since this is approximately the average brightness of the sky, and it may be assumed that the eye has become adapted to endure such a brightness without discomfort. Such recommendation, if followed, would obviate objectionable glare and marked shadows and would insure a certain amount of diffuse illumination.

Other conditions were laid down as to the light emitted by the lighting unit, by specifying the percentage of the amount of light that should be emitted at different angles from the unit, so that the proper illumination would obtain on the horizontal working plane and also on the vertical face of the letter separation cases (1, p. 104).

TABLE 3.—AVERAGE SPEED (NUMBER OF CARDS SORTED PER MINUTE) FOR TESTS UNDER DIFFERENT ILLUMINATIONS IN THE NEW YORK CITY HALL POST OFFICE

GROUP	NUMBER OF CARDS SORTED PER MINUTE				
	2.8 foot candles	3.6 foot candles	8.0 foot candles	14.0 foot candles	2.8 foot candles
A	51.8	55.8	60.4	59.1	57.1
B	52.8	62.5	66.3	65.5	61.9
C	45.4	55.3	57.5	59.2	56.3
Mean for B and C combined	47.6	57.5	60.1	61.2	58.0
Mean for A, B, and C combined	49.7	56.6	60.3	60.1	57.6

Discussion of Possible Tests for Desirable Illumination

It is not an easy matter to determine just how much illumination is necessary, or, let us say, desirable, for a certain kind of work, although it has long been recognized that for the same degree of efficiency one kind of eye work may require more illumination than another; for instance, sewing with black thread on dark cloth requires more illumination than similar work on white material. The reflecting factors of the materials worked on and the degree of discrimination of detail required in the work have much to do with the amount of illumination that will be required to accomplish the work in a short time and with ease. For instance, in the "Code of Lighting for Factories, Mills, and Other Work Places," the advisory commission of the Council of National Defense (3) recommended for rough manufacturing, such as rough machining, rough assembling, and rough bench work, 2 to 4 foot candles; for fine manufacturing, such as fine lathe work, pattern and tool making, and work on light-colored textiles, 4 to 8 foot candles; for special kinds of fine work, such as watchmaking, engraving, drafting, and work on dark-colored textiles, 10 to 15 foot candles.

Since more than 75 per cent. of the work performed in the post offices is of a clerical nature, consisting of the reading of addresses on mail and of similar work in offices, it should require at least as much illumination as would be required for ordinary clerical work.

Three ways of determining the desirability or sufficiency of a given degree of illumination suggest themselves:

1. We may examine the condition of the eyes of a group of people who have been working under the given illumination, and compare it with that of a group doing the same kind of work under a higher illumination. This is the method that we followed in com-

paring the efficiencies of the illuminations in the New York City Hall and general post offices.

2. We may have the workers perform a suitable task under two illuminations differing only in intensity and thus determine under which illumination they can perform it most rapidly. This is the method which we carried out in our card sorting tests in the New York City Hall post office, and which has been used by many other investigators, notably by Cohn (4); Ferree and Rand (5); Luckiesh, Taylor, and Sinden (6); Hess and Harrison (7); and Cobb (8).

3. We may measure the fatigue of the eye of persons working on the same task under different degrees of illumination. The measurement of the fatigue of the eye is a very difficult matter but has been attempted by a few investigators. Ferree and Rand (9) (5) have used the power to sustain clear seeing as a measure of fatigue. The subject observed the object "li" continuously for three minutes. The ratio of the time it was seen clear to the time it was seen blurred was taken as a measure of the power to sustain clear seeing, and the difference between the power to sustain clear seeing at the beginning and at the end of the task was taken as a measure of the ocular fatigue. Ferree and Rand have compared by this method the eye fatigue produced by different systems of lighting.

Büttger (10) has used the involuntary winking of the eyelid as a measure of ocular fatigue, and states that he found it to be a fairly good criterion. A few observations made in the Office of Industrial Hygiene and Sanitation of the United States Public Health Service have shown that each individual has a characteristic rate of involuntary winking; that the rates vary widely for different individuals; and that the rate is greatly increased by ocular fatigue. It has been objected by critics of this method that the rate of involuntary winking is influenced by too many causes other than fatigue to be a reliable measure of it, and further investigations of the method to determine its degree of usefulness appear to be desirable.

Another method, recently used by Cobb and Moss (11), depends on the effect of fatigue in disturbing the muscular balance of the eye. The divergence of the axis of the eye from its normal direction is measured before and after the performance of exacting eye work, and the difference in the degree of divergence in the two cases is taken as a measure of the eye fatigue produced by the task. Using this method they have shown that, other things being equal, the eye is not more fatigued under an illumination of 100 foot candles than it is under an illumination of 5 foot candles, when viewing a black spot on a white background.[2]

Mail Sorting Tests

In order to obtain more definite information as to the effect of increased illumination on the speed of working in the post office, a further series of tests was made in the New York City Hall post office during the year 1923, by the Post Office Department, the Supervising Architect's Office of the

[2] Actually, the brightnesses of the white surface were 100 and 5 millilamberts, respectively.

Treasury Department, and the United States Public Health Service (12), jointly.

Six series of tests were made during the course of the year, each series being made under a different degree of illumination and extending over three or four days. The amount of mail sorted by each one of eight clerks in the dispatching division, and by each one of eight clerks in the delivery division was weighed every half hour. In the dispatching division the illuminations varied from 3.3 to 7.7 foot candles, and in the delivery division from 3.3 to 5.9 foot candles. The results are shown graphically in Figure 3, where curves 1 and 2 represent the results obtained in the dispatching and delivery divisions, respectively. It will be seen that the average rate of production in the delivery division is only about one-half of that attained in the dispatching division. This is due principally to the fact that more separations have to be made in the sorting of mail in the delivery division than in the dispatching division, fifty in the former, and thirty-four in the latter.

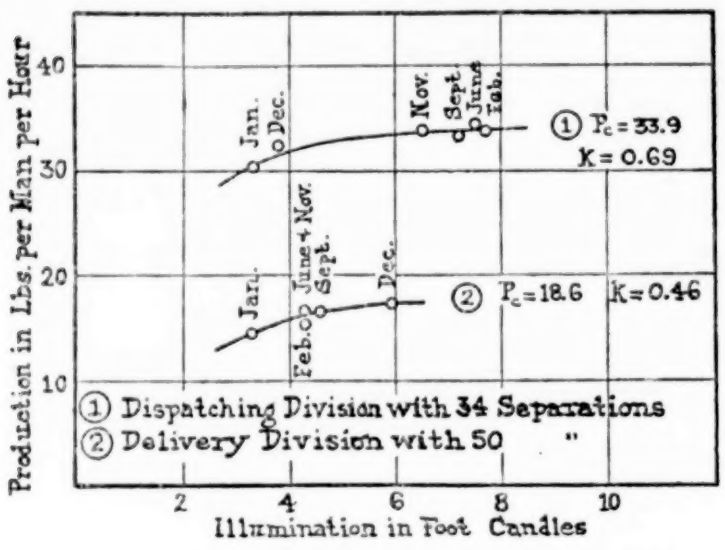

FIG. 3.—Results of tests in the New York City Hall post office on the relation of illumination to production, with curves conforming to the formula $P = P_c(1-e^{-kI})$. In order to make clear the chronologic order in which the tests were made, the date of each test is marked against its corresponding point on the graph.

It will be seen from the graphs that there was a very decided increase in the speed of sorting as the illumination was increased; in the dispatching division an increase of 12 per cent. in speed when the illumination was increased from 3.3 to 7.2 foot candles, and in the delivery division an increase of 20 per cent. when the illumination was increased from 3.3 to 5.9 foot candles.

A Proposed Formula.—From an inspection of the graphs it is evident that they are not parts of logarithmic curves, parabolas, or hyperbolas. Their shape, however, suggests the well-known curve, which, in the present case, would be expressed by the equation

$$P = P_c\left(1 - e^{-kI}\right) \qquad (1)$$

where P would represent the value of the production rate in pounds per man per hour; P_c, a constant value which the production rate approaches as the illumination increases; e, the base of the natural system of logarithms, equal to 2.718; k, a constant which determines the slope of the curve; and I, the illumination in foot candles. If this equation does express the relation of production to illumination within the range of illumination covered by these tests, P_c will represent the production under relatively high illuminations, such as the illumination out of doors under daylight, or in a room which is well lighted by daylight. From the equation it would then appear that, within the range of ordinary working illuminations, say from 1 to 1,000 foot

candles, either indoors or out of doors, so far as the influence of illumination alone is concerned, the production rate will increase with increase in illumination—increasing at first very rapidly and then slowly, and approaching, at an intensity of illumination which will depend on the nature of the work being performed and which will be somewhere between 10 and 100 foot candles, a value which for all practical purposes may be regarded as constant, being the production rate under good daylight illumination. According to this view, if glare is avoided, the production rate will steadily increase with the illumination until it reaches the value for full daylight, after which it will remain practically constant as the illumination is further increased.

It will be observed that in the formula given by equation 1 there are two constants, P_c and k. P_c, as already explained, is the value of the production rate under good daylight illumination, and k is a constant which depends on the nature of the work and the physical and mental characteristics of the worker and which determines the steepness of the curve; the greater the value of k, the more rapidly the curve will rise.

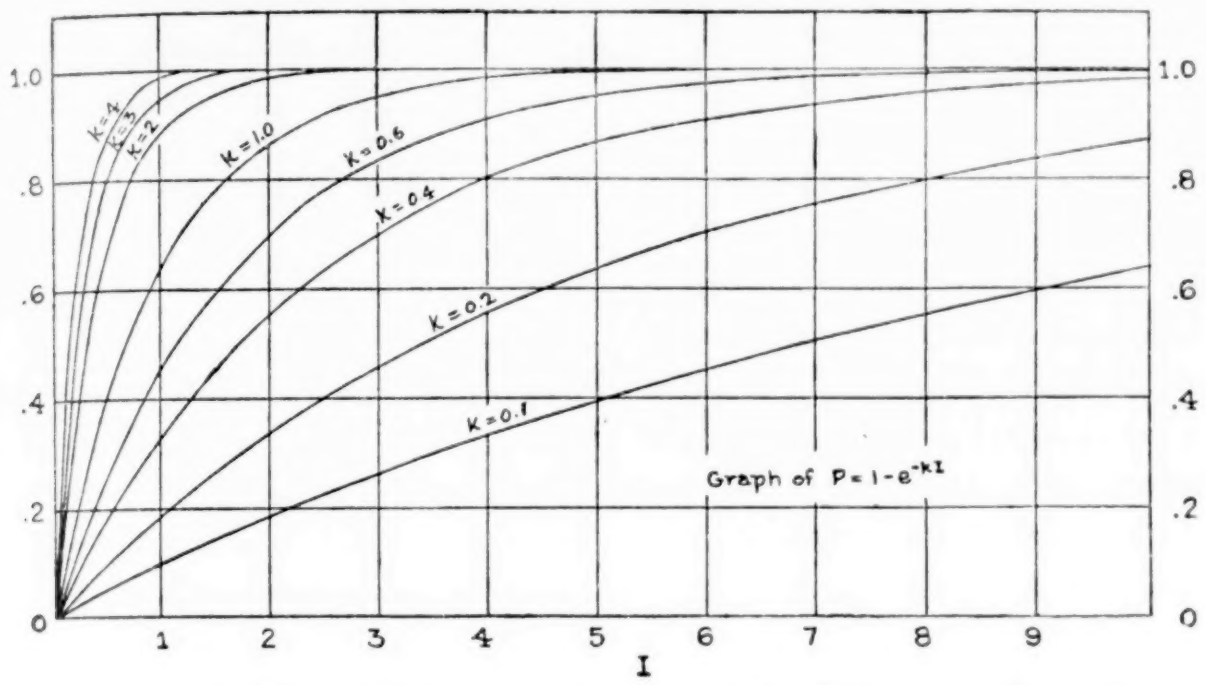

FIG. 4.—Graphs of the function $P = 1 - e^{-kI}$, for different values of k.

If P_c is taken equal to 1, the function P becomes

$$P = 1 - e^{-kI} \qquad (2)$$

In Figure 4 graphs of this function[7] for $P_c = 1$ have been plotted for $k = 4$, 3, 2, 1, 0.6, 0.4, 0.2, and 0.1, respectively.

By suitably choosing P_c and k, calculated curves can be obtained which agree very closely with the curves 1 and 2 of Figure 3. The values of the constants for the calculated curves were obtained by the "cut and try" method. If we take for curve 1, $P_c = 33.9$ and $k = 0.69$, and for curve 2, $P_c = 18.6$ and $k = 0.46$, we obtain calculated values which differ from the experimental values by less than 1 per cent. (12, p. 2832; Table 21, p. 2851).

Even if the smooth curves shown in Figure 3 do not represent *accurately* the law governing the relation between production rate and illumination, sev-

eral considerations indicate that the relation must be of this general character, since it is evident that, when the illumination is zero, the production rate will be zero; that the production rate will increase more rapidly at the lower illuminations than at the higher; and that it is likely that under abundant daylight illumination the rate of production will reach its greatest value, which will be independent, or nearly independent, of small changes in illumination. Such a relation could, of course, be expected to hold only within the ordinary ranges of illumination, either natural or artificial.

The influence of k on the rapidity with which the function P, the production rate, approaches its greatest value may be seen very clearly from the curves of Figure 4. For $k = 1$, the production rate for all practical purposes has reached its greatest value at 8 foot candles; for $k = 0.6$, at 8 foot candles it is 1 per cent. below it; for $k = 0.4$, 4 per cent. below it; and so on.

The nature of the work and the physical and mental characteristics of the worker determine therefore how great the intensity of the illumination must be in order that the production rate shall reach a certain percentage of its maximum value. The more difficult the visual task, and the greater the concentration of vision required, the smaller will be the value of k, and the more slowly will the production increase with the illumination. The difficulty of the visual task will depend on the contrast between the object to be observed and its background, and on the visual angle subtended by the object, *i.e.*, on its size. The value of k will also depend, as already stated, on the physical and mental characteristics of the person sorting; *viz.*, on his visual acuity, on his speed of vision, and on his mental and muscular alertness.

Every form of production is periodic, consisting of the continuous repetition of some elementary operation, which requires a certain time for its performance. This time we may call the *period* of the operation.

In the case of letter sorting, the period, which we may denote by T, is made up of three parts: the average time taken by the clerk to read the address, the average time taken by him to think what pigeonhole to put the letter into, and the average time taken by him to move his hand from the position of rest to the pigeonhole and back again. These three parts of T may to a certain extent overlap each other.

The degree of illumination will probably have a much greater influence on the first part of the time than on the second or the third part, and as a first approximation we may assume that the values of the last two parts are independent of the degree of illumination. The third part of the time will depend on the speed with which the letter separator moves his hand and on the size, number, and arrangement of the pigeonholes in the case.

All processes of production involve manual labor to a greater or lesser degree. In some processes the manual element is reduced to a minimum, a machine performing nearly all the work, and supervision only being required. In general, however, the process of production is made up of

two parts, one part dependent on the use of the eyes and involving the illumination, and the other part not dependent on the use of the eyes and not involving the illumination. In the case of blind people, the whole process of making brooms or caning chairs is of the latter character.

In the case of letter separating, we may divide T into two parts, T_1 and T_2, where T_1 is dependent on the illumination and T_2 independent of it. We may then write

$$T = T_1 + T_2 \qquad (3)$$

T_1, the average time taken by the clerk to read the address, will depend on the amount of matter to be read on the envelope, the clearness with which it is written, the color and nature of the envelope, and the intensity of the illumination.

Under high artificial illumination, or under good daylight illumination, we may assume, as already pointed out, that the production rate, and therefore the period, becomes constant. For high illumination, equation 3 therefore becomes

$$T_c = T_{1c} + T_2 \qquad (3a)$$

in which T_c is the whole period under high illumination, T_{1c} that part of it which depends on the illumination, and T_2, as before, that part of it which is independent of the illumination.

A little consideration of the problem will make it evident that the value of k will depend largely on the proportion of the elementary period which is spent in eye work and on the proportion which is spent in purely muscular or mechanical work, or, in other words, on the relative values of T_{1c} and T_2.

An interesting side light is thrown on the meaning of the formula given in equation 1 by finding the rate at which the production rate varies with the illumination. Differentiating P with respect to I, we get

$$\frac{dP}{dI} = k\,(P_c - P) \qquad (4)$$

or the rate at which the production rate varies with the illumination, for any given illumination, I, is directly proportional to the difference between the production rate, P, for that illumination, and the greatest possible value of the production rate, P_c, k being the constant of proportionality. Here k may be regarded as a measure of the ocular ease of the task. The greater the ocular ease of the task, the greater k will be. The ocular ease of the task will be increased, principally, by increasing the contrast between the object observed and its background, by increasing the visual angle subtended by the object, and by increasing the ratio of T_c to T_{1c}.

Recent Tests Made in Washington and a Modification of the Proposed Formula

If the formula proposed in equation 1 holds for the relation of the production rate to illumination, it is of interest to determine what happens to the production rate when the illumination is very low. Some card sorting tests made recently in Washington seem to throw light on the matter.

The ocular task was simple and easy. Each of forty white cards had a number consisting of ten digits typewritten in black on the middle of it. The digits were written on an Underwood typewriter especially designed for statistical work; each digit was 2 mm. high and 1.6 mm. broad;

together they occupied a total space of 24.5 mm. Ten of the cards had 1 zero in the number; ten, 2 zeros; ten, 3 zeros; and the other ten, 4 zeros. On none of the forty cards, however, were the digits arranged in the same order. The task was to sort the forty cards into four piles so that all the cards in a pile should have the same number of zeros. After the cards had been sorted according to the number of zeros and the number of errors made in the sorting had been determined, the cards were twice distributed into four piles without looking at the numbers on them. The objects of the latter procedure were (1) automatically to mix the cards so that no two cards having the same number of zeros would be consecutive in the next sorting; (2) to determine what portion of the time had been taken

TABLE 4.—SPEED OF SORTING (NUMBER OF CARDS SORTED PER MINUTE) AND SPEED OF DISTRIBUTION, UNDER DIFFERENT ILLUMINATIONS, FOR RECENT TESTS IN WASHINGTON, TOGETHER WITH THE NUMBER OF ERRORS MADE IN EACH TEST

A.F.B.				R.H.B.				S.D.C.				D.K.B.			
Illumination in Foot Candles	Speed of Sorting	Number of Errors	Speed of Distributing	Illumination in Foot Candles	Speed of Sorting	Number of Errors	Speed of Distributing	Illumination in Foot Candles	Speed of Sorting	Number of Errors	Speed of Distributing	Illumination in Foot Candles	Speed of Sorting	Number of Errors	Speed of Distributing
.....	....	..	....	27.5	58.0	0	109	29.1	33.4	1	79.0	26.7	32.9	1	115
7.8	34.8	0	78.0	7.8	58.6	0	118	8.1	31.7	0	78.7	7.6	31.7	1	116
3.9	38.6	..	72.6	4.2	58.6	1	101	4.4	33.3	0	81.9	4.4	33.0	1	112
2.6	36.5	2	76.0	3.1	58.3	0	116	3.0	33.1	1	86.3	2.8	26.9	0	116
1.5	31.6	0	79.5	1.8	59.4	0	107	1.8	32.3	0	82.2	1.6	29.1	0	109
0.9	32.7	0	79.7	1.0	57.2	0	111	1.0	32.6	0	82.2	0.98	27.8	1	105
0.74	31.9	0	78.0	0.71	57.7	2	115	0.78	29.0	1	83.3	0.62	25.3	0	114
0.24	27.9	0	82.3	0.28	50.6	1	102	0.22	28.1	0	92.7	0.19	20.6	1	113
0.087	25.9	1	84.5	0.088	46.2	0	114	0.061	16.0	0	88.3	0.056	19.7	0	109
0.062	24.9	1	83.6	0.062	46.9	0	115	0.033	9.0	19	82.2	0.023	17.7	1	107
0.019	22.2	0	81.4	0.014	34.4	0	110	0.061	13.8	1	86.3	0.012	15.9	0	116
0.061	25.6	0	80.9	0.004	18.6	4	103	0.22	23.4	0	86.9	0.008	11.9	2	113
0.106	28.0	1	86.0	0.02	37.5	1	107	0.74	29.2	0	88.9	0.012	13.3	1	106
0.29	33.5	1	84.5	0.064	47.1	0	111	1.0	30.7	0	94.2	0.023	19.7	0	99
0.72	29.8	0	84.8	0.1	46.9	1	111	1.7	34.4	2	93.0	0.057	21.3	0	117
0.94	31.6	1	94.9	0.26	51.1	1	111	3.0	30.7	0	90.3	0.18	24.5	0	110
1.6	34.3	0	89.9	0.63	53.1	1	116	4.4	34.4	0	87.9	0.6	24.8	0	112
2.7	37.5	0	88.2	1.09	54.6	2	119	8.0	35.2	2	94.9	1.0	28.6	0	114
4.2	36.9	0	90.6	1.6	57.5	0	108	30.5	35.2	2	103.0	1.7	27.9	0	121
7.4	40.0	0	91.9	3.1	55.1	1	114	.....	....	..	.....	2.8	28.2	0	122
.....	....	..	....	4.9	54.8	0	112	.....	....	..	.....	4.2	30.0	0	121
.....	....	..	....	8.0	54.8	0	112	.....	....	..	.....	7.4	28.8	0	124
.....	....	..	....	32.2	55.3	1	118	.....	....	..	.....	27.5	30.6	0	130

up by the purely mechanical part of the process—that is, to determine the value of T_2 in equations 3 and 3a; without looking at the numbers on them will hereafter be referred to as *distribution* in order to distinguish

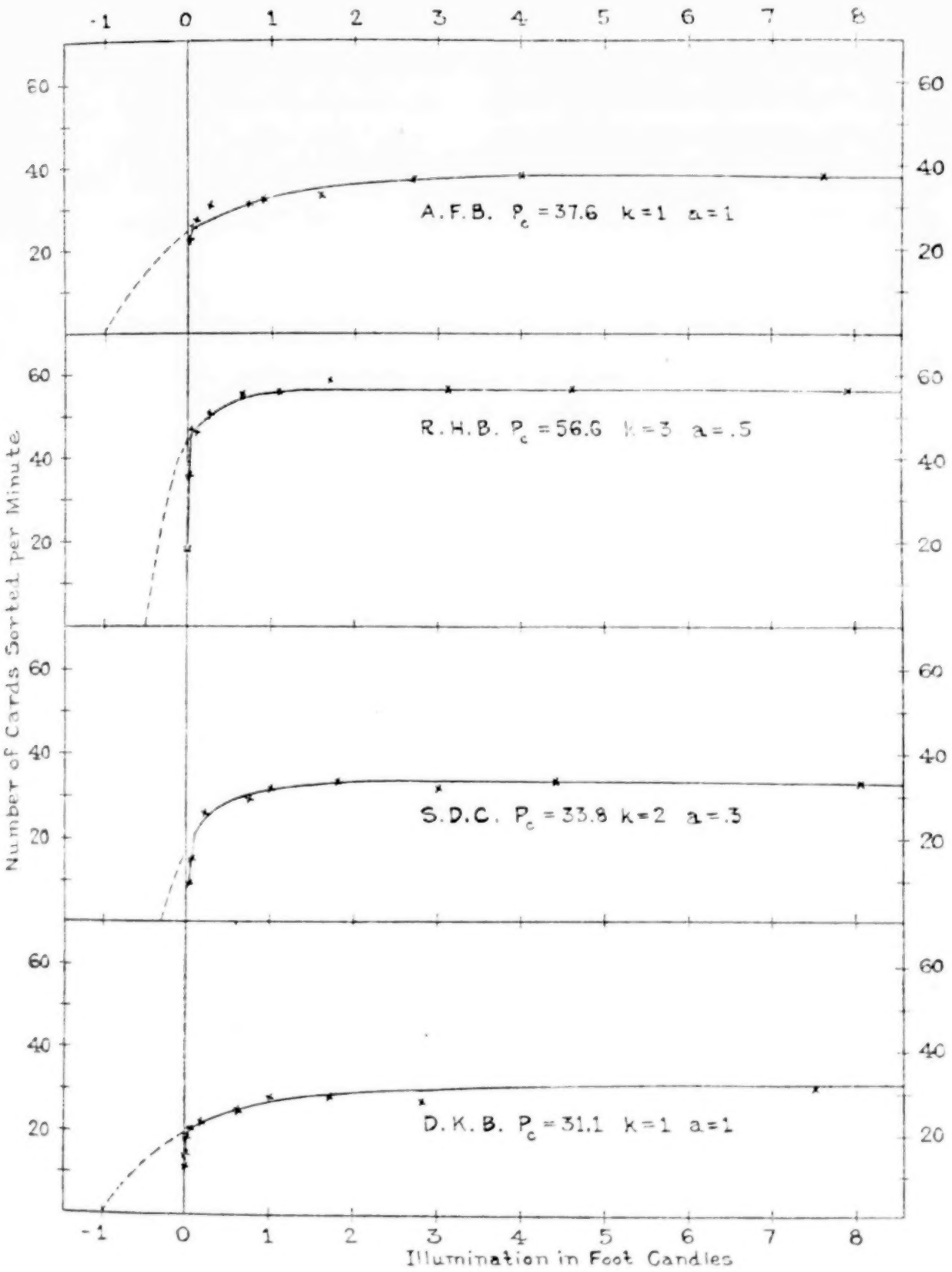
-1 0 1 2 3 4 5 6 7 8
60
40
20
A.F.B. P_c = 37.6 k = 1 a = 1
R.H.B. P_c = 56.6 k = 3 a = .5
S.D.C. P_c = 33.8 k = 2 a = .3
D.K.B. P_c = 31.1 k = 1 a = 1
Number of Cards Sorted per Minute
Illumination in Foot Candles

FIG. 5.—The solid portions of the curves represent the results of the card sorting tests made recently in Washington in order to determine the relation of speed of sorting to illumination. The broken portions of the curves, to the left of zero illumination, conform to the formula $P = P_c(1-e^{-k(I+a)})$.

and (3) to give some information as to the effect of learning, habit, and fatigue on the results of the test. The separation of the cards into four piles it from *sorting* of the cards according to the number of zeros.

The illumination varied through a wide range, its highest value being

about 30 foot candles and its lowest, only a few thousandths of a foot candle.

Four males, varying in age from 34 to 37 years, and all having a visual acuity of 20/20, with or without glasses, were tested. Only one, S.D.C., wore glasses during the tests. The results of these tests are shown in Tables 4 and 5, and by the solid portions of the curves in Figure 5.

In Table 4 the initials are those of the persons tested. In the first column under each initial are the illuminations in foot candles under which the tests were made; in the second column, the number of cards sorted per minute under that illumination; in the third column, the number of errors made during the test; and in the fourth column, the number of cards distributed per minute into the four piles without looking at the numbers on them. As will be seen from the table, the illumination was successively decreased from the greatest value to the least, and then successively increased to the greatest value, giving two tests under approximately the same illumination.

In the first column of Table 5 corresponding values for decreasing and increasing illuminations have been averaged; in the second column the corresponding speeds of sorting have been averaged; in the third are given indices of the speed of sorting, the base 100 being the average speed under the three highest illuminations, approximately 30, 8, and 3.5 foot candles. These indices of the speed of sorting are plotted as curves A.F.B., R. H. B., S.D.C., and D.K.B. in Figure 6. It will be observed from the curves of Figure 6 that the effect of reducing

TABLE 5.—MEAN SPEED OF SORTING UNDER DIFFERENT ILLUMINATIONS, TOGETHER WITH THE SPEEDS REDUCED TO AN INDEX BASE OF 100

A.F.B.			R.H.B.			S.D.C.			D.K.B.		
Mean Illumination in Foot Candles	Mean Speed of Sorting	Index of Mean Speed of Sorting	Mean Illumination in Foot Candles	Mean Speed of Sorting	Index of Mean Speed of Sorting	Mean Illumination in Foot Candles	Mean Speed of Sorting	Index of Mean Speed of Sorting	Mean Illumination in Foot Candles	Mean Speed of Sorting	Index of Mean Speed of Sorting
.....	....	...	29.8	56.6	100	29.8	34.3	101	27.1	31.7	102
7.6	37.4	100	7.9	56.6	100	8.0	33.3	98	7.5	30.2	97
4.0	37.7	100	4.6	56.6	100	4.4	33.8	100	4.3	31.4	101
2.7	36.9	98	3.1	56.6	100	3.0	31.9	94	2.8	27.6	89
1.6	32.9	88	1.7	58.4	103	1.8	33.3	98	1.7	28.5	92
0.92	32.1	85	1.1	55.8	99	1.0	31.7	94	1.0	28.2	91
0.73	30.8	82	0.67	55.2	98	0.76	29.1	86	0.61	25.0	80
0.26	30.7	82	0.27	50.8	90	0.22	25.6	76	0.18	22.4	72
0.096	27.0	72	0.094	46.5	82	0.061	14.8	44	0.056	20.5	66
0.062	25.2	67	0.063	46.9	83	0.033	9.0	27	0.023	18.7	60
0.019	22.2	59	0.017	35.9	63	.....	....	...	0.012	14.5	46
.....	....	..	0.004	18.5	33	.....	....	...	0.008	11.9	38

the results of the tests to an index basis is to make the value of P_c the same for each individual, making it possible to compare the curves with each other and with those of Figure 4, which represent the formula

$$P = 1 - e^{-kI}$$

The subject was seated with the source of light about 1 foot above his head, so that there was no shadow cast on the cards and no glare in his eyes. The illumination was obtained by the use of bare Mazda C and Mazda B lamps of different wattages, beginning, for the highest illumination, with a Mazda C lamp of 100 watts and ending with a Mazda B lamp of 15 watts. Further reduction in the illumination was obtained by using a screen of tracing cloth beneath the 15-watt lamp and covering it successively with 1, 2, 3, 4, and 5 sheets of thin white paper.

The dimensions of the room in which the tests were made were 15 feet by 12 feet, 6 inches, with a height of 9 feet. The ceiling and walls were of a light French gray. The subject was seated at a table placed in the middle of the room. As a result of the manner in which the illumination was obtained, the ceiling and walls had for all the tests an illumination of the same order as that on the cards being sorted, so that a sharp contrast in illumination between the objects worked on and the surroundings was avoided.

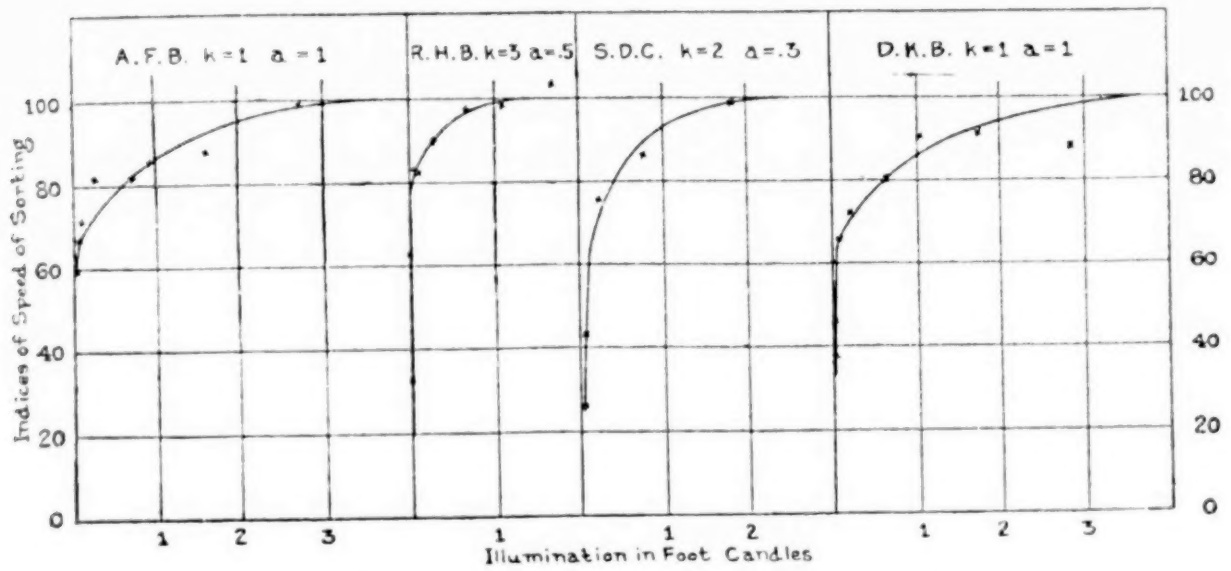

FIG. 6.—Results of speed of sorting tests reduced to index numbers so that they may be compared with the graphs of Figure 4.

The time taken to sort and to distribute the forty cards was measured with a stop watch.

An inspection of Table 4 and Figure 5 shows that in all cases the speed of sorting suffered no appreciable change as the illumination was decreased from about 30 foot candles until an illumination of about 3 foot candles was reached, when indications of decreased production began to appear for A.F.B. and D.K.B.; S.D.C. did not show marked decrease of production until 2 foot candles was reached; and R.H.B., not until 1 foot candle. The reaching of steady values of the production at the relatively low illuminations of 3, 2, and 1 foot candles, respectively, is explained by the fact that the ocular task was an easy one. In the letter sorting tests the ocular

task was more difficult and the production did not reach a steady value until, as is shown in Figure 3, the illumination attained values of 6 and 8 foot candles, respectively.

A striking feature of all the curves is that they may, for all practical purposes, be said to cut the Y axis at a value of the illumination considerably greater than zero. Comparing the index curves of Figure 6 with the curves of Figure 4, representing the formula

$$P = 1 - e^{-kI}$$

we see that any one of them may be made to fit closely one of the curves of Figure 4 by shifting it a bit to the left, which is tantamount to modifying the formula given in equation 2 by adding to the variable I a small constant, a. The formula then becomes

$$P = 1 - e^{-k(I+a)}$$

For instance, the curve for A.F.B. on Figure 6 fits the curve for $k = 1$ on Figure 4 if we take $a = 1$, that is, if we take the origin of curve A.F.B. 1 foot candle to the left of zero illumination. In the same way curves for R.H.B., S.D.C., and D.K.B. may be made to fit the curves for $k = 3$, $k = 2$, and $k = 1$ on Figure 4, if we take for these graphs $a = 0.5$, 0.3, and 1, respectively. It will be noted that for the larger values of the illumination, *i.e.*, for values greater than 4 or 5 foot candles, the addition of this constant to I would not have much effect on the shape of the curve.

The dotted portion of the curve, to the left of zero illumination, of any one of the curves in Figure 5 represents the amount by which the curve, given by the formula

$$P = P_c\left(1 - e^{-kI}\right)$$

has been shifted to the left. The negative intercept on the X axis is evidently equal to a, the amount of the shift.

It is realized that to obtain accurate values of k and a for any particular person it would be necessary to make a number of tests for this person; but the values given illustrate the theory and the method employed to determine the values of the constants.

Further Investigations Suggested

Although much has been learned from the tests conducted thus far on post office lighting, it is felt that a number of matters need further study. Among these may be mentioned:

First, the phenomenon of the lag in the production, that is, that when the illumination is decreased or increased the production rate does not rise or fall immediately to the value corresponding to that illumination, but rises or falls to it only after the new illumination has been maintained for a certain length of time.

This phenomenon was observed during the course of the tests in the New York post offices (1, pp. 91–93), where it was noted that although the rate of sorting cards increased with increase of illumination and decreased when the illumination was reduced to its original value, the rate of sorting did not fall to its original value but still remained about 16 per cent. above it. Dr. E. F. Nichols (7, p. 800) has suggested that this lag in the pro-

duction rate might have been due to the development of a habit of faster work, which was not immediately shaken off when the illumination was reduced to its former value. This failure of the production rate to return to its original value was also noted in a similar experiment in England in regard to coal production (13). When the coal miner used an ordinary lamp, the production was 2.47 tons; with a lamp six times as bright, it was 2.83 tons, an increase of 14.6 per cent. When the miner returned to the ordinary lamp, the production did not return to its original value but still remained 4 per cent. above it. The same thing was also observed during the 1923 tests in the New York City Hall post office (12, pp. 2830–2831).

Second, the question as to whether, when the production has been increased by increased illumination, this increase will be maintained or will gradually become less.

And third, the determination of the fatigue of the eye under different degrees of illumination, for the purpose of determining what degree of illumination will produce the least ocular fatigue.

Studies in connection with these three problems are now being carried on by the United States Public Health Service in the main post office in Chicago, and it is expected that valuable results will be obtained from them.

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REPORT ON TETRAETHYL LEAD

January 17, 1926.

Surgeon General H. S. Cumming,
United States Public Health Service,
Washington, D. C.

Dear Sir:

The committee appointed by you at the request of the conference held in Washington May 20, 1925, was directed to present to you "if possible by January first next, a statement as to the health hazards involved in the retail distribution and general use of tetra-ethyl lead gasoline motor fuel." As soon as practicable after its appointment, the committee met in your office for organization and for discussion of the procedure to be followed in carrying out its instructions.

The members of the committee familiarized themselves, as far as possible, by conferences and by reading, with the existing data bearing upon the subject and upon lead poisoning in general. They had access to the stenographic report (See U. S. Public Health Bulletin No. 158) of the addresses and discussions which took place at the conference of May 20, and subsequently they made a personal examination of the plant at Deep Water, N. J., for the manufacture of tetra-ethyl lead, and of one of the stations at which the ethyl fluid is mixed with gasoline.

Ethyl gasoline was first placed on sale February 1, 1923, and its sale was voluntarily discontinued May 5, 1925, about 300,000,000 gallons of ethyl gasoline being distributed during this period. Serious cases of poisoning occurred among men handling lead tetra-ethyl and ethyl fluid in the States of New Jersey and Ohio. As far as the committee is aware these accidents had all occurred in connection with the manufacture and blending of concentrated tetra-ethyl lead, and threw no direct light upon the problem specifically laid before us—that of the retail distribution and general use of ethyl gasoline. The valuable experiments reported by the U. S. Bureau of Mines and by investigators at Columbia University and others yielded important results, but we felt that the crucial test of the situation must be derived from actual experience in the use of ethyl gasoline under practical conditions of operation.

It was therefore decided that the committee should make a direct investigation of the question submitted to them, planning the work on as extensive a scale as was possible in the time allowed. Fortunately this mode of approach was made feasible by the fact that ethyl gasoline has been in constant use as a motor fuel in certain parts of Ohio for several years; and although the production and distribu-

tion of tetra-ethyl lead and ethyl fluid had been suspended by the voluntary action of the manufacturers, pending the present investigation, it was known that in the region indicated, a supply of ethyl fluid was still in the hands of certain consumers and would be continued in use. We were thus presented with an opportunity of studying a fairly large group of individuals who had been using and handling ethyl gasoline and of comparing the findings upon them with the examination of a similar group employing gasoline free from lead.

In several conferences, the committee, with the assistance of Surgeon General Cumming and Surgeon L. R. Thompson, U. S. Public Health Service, in charge of the section of Industrial Hygiene and Sanitation, formulated a general plan of investigation. The actual conduct of the work was entrusted to Doctor J. P. Leake, Surgeon, U. S. Public Health Service, who at once organized a corps of workers and began observations upon certain groups of individuals in Dayton and Cincinnati. The committee desires to express its appreciation of the cordial cooperation extended to this group of observers by both the employers and workers in the garages selected for the investigations. After all the preliminary arrangements had been completed, the work was pushed with great vigor during the autumn months, and on December 19, Doctor Leake presented to the committee a full report of the results of his study. The committee wishes to express its great satisfaction with the promptness, energy and ability with which these investigations were carried out. The general character and scope of the work may be summarized briefly as follows:

Two hundred and fifty-two individuals were studied. They were all adult males, and fall into five groups.

1. Group A, a control group, consisted of thirty-six men who were employees of the City of Dayton. Their duty was to drive cars during the working day. In these cars the gasoline used contained no lead. The cars were housed in the municipal garage, which in the report is designated as the Dayton Control Garage.

2. Group B, a test group, consisted of seventy-seven men who were employees of a public service corporation in Dayton, and whose duties were similar to those of Group A. The cars that they drove, however, used ethyl gasoline, and this fuel had been in constant use in this service since July, 1923. The garage in which these cars were housed is designated as the Dayton Test Garage.

3. Group C, a control group, consisted of twenty-one men. These were employed as garage workers in the Dayton Control Garage or in a similar control garage in Cincinnati, or as gasoline fillers at service stations or on trucks delivering gasoline in Dayton and the adjoining region. In none of these garages, service stations, or trucks was gasoline containing lead used or handled.

4. Group D, a test group, consisted of fifty-seven men. These were employed as garage workers in the Dayton Test Garage or in a similar test garage in Cincinnati, or as gasoline fillers at service stations, wholesale gasoline plants, or on trucks delivering gasoline in Dayton, Cincinnati, and vicinity. The duties of these men were similar to those of Group C except that ethyl gasoline was handled in the garages, stations, and trucks.

5. Group E, a control group, consisted of sixty-one men employed in two industrial plants of entirely different character from the foregoing in which there was known to be a serious exposure to lead dust. Numerous cases of lead poisoning had occurred in these plants. This group was selected to serve for what might be called a positive

control or check in regard to the validity of the clinical and analytical methods used in the study of the individuals of Groups A, B, C, and D.

Methods Used

Each individual was subjected to a careful clinical examination, and in addition, smears were made from his blood and a specimen of his feces was collected. The blood smears and the fecal specimens were sent to Washington to be examined by trained experts for stippling of the red cells and for content in lead. The examination of the feces for lead was made by chemists who had been especially trained in the technique of the method. The blood examinations were made by a group of skilled observers, and were arranged so that the counts in each case were checked by several workers.

The clinical examination was conducted by four physicians. The first of these took a careful industrial history of each subject, and assigned to him a certain number. These numbers were taken at random. Thereafter this individual was recorded by his number, and none of those making the subsequent examinations or the laboratory tests knew whether or not the individual had been exposed to ethyl gasoline; nor, in fact, did any examiner, except the one who took the industrial history, know to which group the individual belonged.

After taking the industrial history, other examiners made a thorough medical examination, including a medical history, hemoglobin estimation, red-cell count, blood pressure records, visual acuity tests, urine examinations, etc.; and finally a determination, by a special method devised for the occasion, of the muscular strength of the extensor and flexor muscles of the forearm.

While all of the examinations were made with as much care as possible, special attention was given to three methods which, it was hoped, would yield quantitative data of an objective character. These were, first, the determination of the amount of lead in the feces, as an index of lead ingestion or absorption; second, the estimation of the number of stippled red cells, which, in the absence of other causes, might also be considered as an index of lead absorption; third, measurements of the strength of the extensor muscles of the forearm, as an index of lead poisoning. The two first methods yielded results of positive value, but the last was practically negative so far as the present investigation is concerned.

When all the data had been collected, they were submitted to study and statistical analysis by Doctor Leake and his collaborators, and the results were presented to the committee in the form of a detailed report containing a description of the methods used, tabular summaries of results, and protocols of the findings for each individual studied. This report will be published in full by the Public Health Service. So far as the clinical examinations are concerned, it may be said that they failed to give any decisive indication of lead poisoning among the chauffeurs or workers in garages in which ethyl gasoline was used as a motor fuel (Groups B and D)[1]. The median time of potential

[1] The only injury observed was acute irritation of the eyes in a few cases, due to getting gasoline into the eyes. This occurred both with ordinary gasoline and with ethyl gasoline but was perhaps more severe in one case due to the latter. This case is mentioned specifically in the full report.

exposure among these men approximated two years, and this negative result, therefore, holds good only for a period of this duration. It should be added that in Group E, comprising workers in industrial plants in which there was a known and serious exposure to lead dust, definite clinical symptoms of lead poisoning were revealed, although these workers had been exposed for shorter periods of time.

More significant results were obtained from the analysis of the feces and from the microscopic examination of the blood smears. These results are presented in condensed form in the accompanying graphs and tables. (Graphs 1 to 4 and Tables A, B, C and D.)

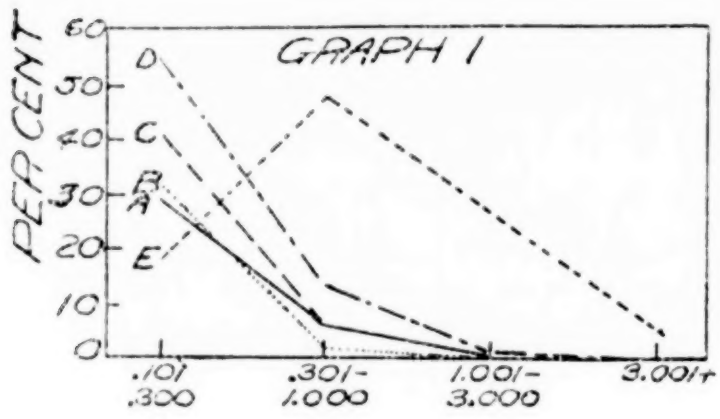
Graph 1 and Table A represent the amount of lead found in the feces of the individuals of Groups A, B, C, D and E. The figures along the abscissa of the graph give the amount of lead in milligrams per gram of ash of the feces, from 0.1 mgm. to 3 mgms. The ordinates represent percentages of the workers in each group. It will be seen that in Groups A and B, representing drivers of cars, one using gasoline without lead and the other the ethyl gasoline, the amount of lead in the feces was practically identical. The exposure of these men was mainly to the exhaust gas from the motors, and it would appear that in Group B, using the ethyl gasoline, there was no positive indication of increased absorption of lead. The fact that in Group A, some lead was also found in the feces, shows that these men were exposed to lead from some other undetermined source. In this connection it is to be noted that twenty examinations were made in Washington by the same methods of the feces of ten of the workers in the Hygienic Laboratory of the U. S. Public Health Service. These workers had had no known exposures to lead but their feces showed at each examination small amounts of lead ranging from 0.047 mgm. to 0.290 mgm. per gram of ash of the feces. In what might be called normal feces, therefore, lead may be present, from accidental exposures of one kind or another, in concentrations not differing materially from those found in Groups A and B.

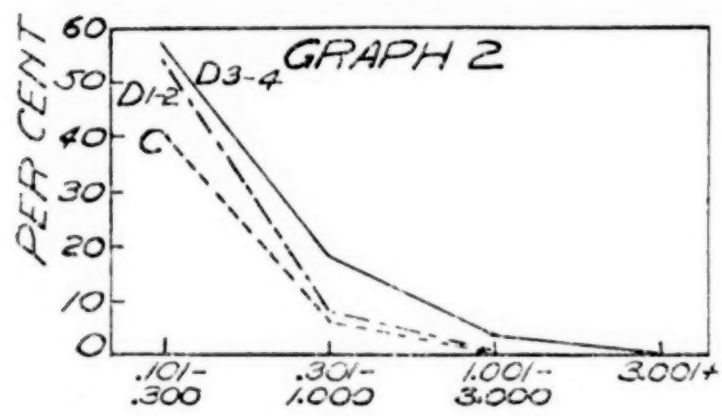
In Group C, representing the garage workers and gasoline handlers not exposed to ethyl gasoline, there is an indication of a slightly greater excretion of lead. In the control garages and repair shops, as will be shown later, there was a perceptible amount of lead in the dust upon the floors and benches.

In Group D, representing the garage workers and gasoline handlers using ethyl gasoline, there is a still further increase in the amount of lead excreted, although the number who showed excretion of as much as 0.3 mgm. per gram of ash is small (15 per cent). It seems probable that this increase was due to the use of ethyl gasoline, since subdivision of this group into two classes, those with a lesser exposure to ethyl gasoline, as regards time and intensity, D1 and 2, and those with a greater exposure, D3 and 4, indicates that in the latter there was greater excretion, as is shown in Graph 2 and Table B.

In Group E, as would be expected, there is evidence of much greater ingestion or absorption. Over 80 per

cent showed more than 0.3 mgm. of lead for each gram of ash of the feces, and in some cases the lead was present





PERCENTAGE OF WORKERS WITH VARIOUS AMOUNTS (ONE TENTH MG. OR MORE) OF LEAD PER GRAM OF ASH IN FECES BY GROUPS

in concentrations as great as 3 mgms. per gram of ash.

Graph 3 (see Table C) gives curves indicating the number of stippled cells found in the blood of the workers in Groups A, B, C, D and E. The abscissa in this case represents the number of definitely stippled cells per 100,000; the curves are plotted for the values 1 to 2 per 100,000, 3 to 6, 7 to 20, 21 to 100.

Here again the results for Groups A and B are practically identical. In each group a small number, 12 per cent, showed definite stippling. No examinations of persons who are neither drivers of cars nor garage workers are available, carried out by the same observers using the same method. It is not possible to say whether the slight degree of stippling observed with Groups A and B pos-

TABLE A—PERCENTAGE OF PERSONS WITH MORE THAN ONE TENTH MILLIGRAM OF LEAD PER GRAM OF ASH IN FECES IN THE EXPOSURE GROUPS A, B, C, D AND E

GROUP	MILLIGRAMS OF LEAD PER GRAM OF ASH			
	0.101–0.300	0.301–1.000	1.001–3.000	3.001 and over
A	29	6	..	..
B	32	2	..	..
C	41	6	..	..
D	56	13	2	..
E	15	49	29	5

TABLE B—PERCENTAGE OF PERSONS WITH MORE THAN ONE TENTH MILLIGRAM OF LEAD PER GRAM OF ASH IN FECES IN GROUP C AND HALF-GROUPS D1-D2 AND D3-D4

GROUP	MILLIGRAMS OF LEAD PER GRAM OF ASH			
	0.101–0.300	0.301–1.000	1.001–3.000	3.001 and over
C	41	6	..	..
D1 and D2[1]	54	8	..	..
D3 and D4	57	18	4	..

[1] D1 and D2 are the two quarters of exposure Group D which had less exposure to ethyl gasoline and ethyl fluid and D3 and D4 are the two quarters which had the greater exposure.

sesses any significance, but it seems to be clear that the members of Group B, exposed to the exhaust gases from engines using ethyl gasoline, showed no

noticeable increase in stippling as compared with Group A.

In Group C there is a distinct increase in the percentage of workers showing stippling, and this increase is more marked in the workers of Group D. These results, therefore, corroborate the findings from the analysis of the feces in suggesting a beginning storage of lead in these two groups. That the greater indicated storage in Group D is connected with the use of ethyl gasoline seems to be borne out by the curves shown in Graph 4 (Table D), in which the curves are plotted for the two classes of Group D referred to above, the workers with the greater exposure showing a very slight increase in the percentage of those exhibiting definite stippling. The curve for the workers in Group E is of an entirely different character. Over 90 per cent showed distinct stippling, and in most of these cases the stippling was relatively very abundant.

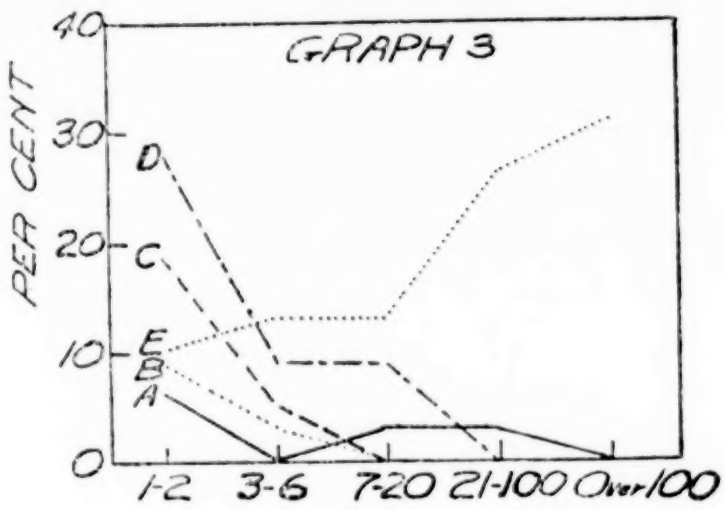
TABLE C—PERCENTAGE OF PERSONS SHOWING DEFINITE STIPPLING OF DIFFERENT DEGREES IN EXPOSURE GROUPS A, B, C, D AND E.

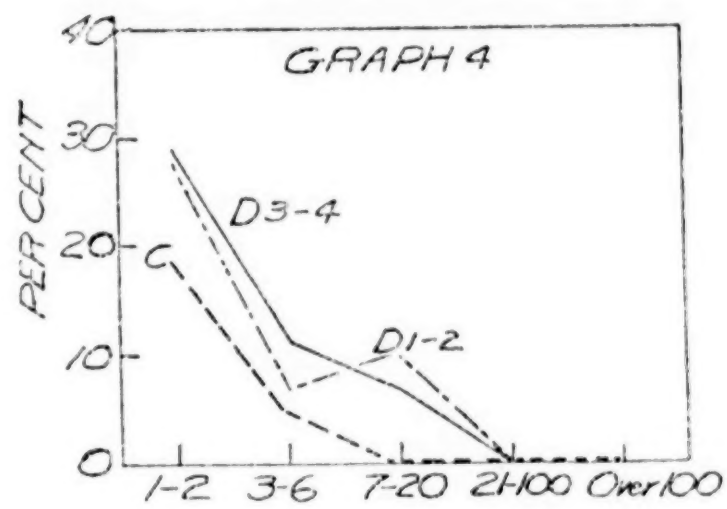
GROUP	STIPPLED CELLS PER 100,000 RED CELLS				
	1–2	3–6	7–20	21–100	Over 100
A	6	..	3	3	..
B	9	3	..	..	..
C	19	5	..	..	..
D	28	9	9	..	..
E	10	13	13	26	31

TABLE D—PERCENTAGE OF PERSONS SHOWING DEFINITE STIPPLING OF DIFFERENT DEGREES IN GROUP C AND HALF-GROUPS D1-D2 AND D3-D4

GROUP	STIPPLED CELLS PER 100,000 RED CELLS				
	1–2	3–6	7–20	21–100	Over 100
C	19	5	..	..	..
D1 and D2[1]	28	8	10	..	..
D3 and D4	29	11	8	..	..

[1] D1 and D2 are the two quarters of exposure Group D which had less exposure to ethyl gasoline and ethyl fluid and D3 and D4 are the two quarters which had the greater exposure.





PERCENTAGE OF WORKERS WITH VARIOUS DEGREES OF STIPPLING (DEFINITE) BY GROUPS

Inquiry into Reported Cases of Injury Resulting from the Use of Ethyl Gasoline

So far as the committee could ascertain, all the reported cases of fatalities and serious injuries in connection with

the use of tetra-ethyl lead have occurred either in the process of manufacture of this substance or in the procedures of blending and ethylizing. It seemed desirable to institute an inquiry in the region where this investigation was made, and where ethyl gasoline had been employed as a motor fuel for the longest time, as to possible cases of injury resulting from its use. All the workers examined were questioned, therefore, in regard to their knowledge of cases of possible injury, and inquiries were made in the Dayton and Cincinnati districts among local health officers, physicians, public health workers, and labor leaders. The few clues obtained from this inquiry were investigated in detail, but the results were negative. No positive evidence could be obtained of harmful effects attributable to the use of ethyl gasoline.

Observations upon the Lead in the Dust and Air of the Garages Investigated and upon the Amount of Carbon Monoxide

In addition to the examinations made upon the workers themselves, some data were collected in regard to the amount of lead in the air and dust of the garages and work rooms, and also in regard to the concentration of carbon monoxide. These observations were made during October, 1925, and owing to the unusually cool weather prevailing during that month, the doors and windows were closed during most of the day. The conditions regarding ventilation were those to be expected for winter rather than summer weather. The several methods employed in this part of the investigation are given in detail in the full report. The findings obtained are summarized in the accompanying tabular statements for the several garages investigated as well as for the industrial plants in which there was a serious exposure to lead dusts. This part of the investigation was not so extensive as was desired, owing to the shortness of the time allowed, but it is evident from the results obtained that some lead was present in the air of the garages and work rooms whether the gasoline used contained lead or not; and in the sweepings of dust from the floors and benches there was a distinct amount of lead present, the figures running from 0.82 mgm. to 22.31 mgms. per gram of dust, according to the time and place of the gathering of the sample. It would seem probable, therefore, that in all garages in which automobiles are being handled and repaired, the workers are constantly exposed to certain amounts of lead dust, and this fact would tend to emphasize the importance of providing such rooms with adequate ventilation, and of keeping both the floors and the benches as free as possible from the accumulation of dust. Owing to the incompleteness of the data, it is not possible to say definitely whether the exposure to lead dust was greater in those garages in which ethyl gasoline was used. It is very desirable that these investigations should be continued.

Conclusions

On the basis of this investigation, the committee feels that the following general conclusions are justified:

1. Drivers of cars using ethyl gasoline as a fuel and in which the concentration of tetra-ethyl lead was not greater than one

part to 1300 parts by volume of gasoline, showed no definite signs of lead absorption after exposures approximating two years.

2. Employees of garages engaged in the handling and repairing of automobiles and employees of automobile service stations may show evidence of lead absorption and storage, as indicated by the lead content of the feces and the appearance of stippled cells in the blood. In garages and stations in which ethyl gasoline was used, the amount of apparent absorption and storage was somewhat increased, but the effect was slight in comparison with that shown by workers in other industries when there was a severe lead hazard (Group E) and for the periods of exposure studied was not sufficient to produce detectible symptoms of lead poisoning.

3. In the regions in which ethyl gasoline has been used to the greatest extent as a motor fuel for a period of between two and three years, no definite cases have been discovered of recognizable lead poisoning or other disease resulting from the use of ethyl gasoline.

In view of these conclusions your committee begs to report that in their opinion there are at present no good grounds for prohibiting the use of ethyl gasoline of the composition specified, as a motor fuel, provided that its distribution and use are controlled by proper regulations. The committee feels that the formulation of specific regulations in regard to the manufacture, distribution and use of tetraethyl lead, ethyl fluid, and ethyl gasoline for adoption and enforcement by the several States belongs properly to the office of the Surgeon General of the Public Health Service. In an appendix to this report, attention is called to certain suggestions which have been made in the course of the discussions of this committee and which it is believed should be taken into consideration in making such regulations.

In conclusion we beg to say that we are conscious of the fact that the conclusions to which we have come in this report, although based upon most careful and conscientious investigations, are subject to the criticism that they have been derived from the study of a relatively small number of individuals who were exposed to the effects of ethyl gasoline for a period of time comparatively brief when we consider the possibilities in connection with lead poisoning. A more extensive study was not possible on account of the limited time. It remains possible, that if the use of leaded gasoline becomes widespread, conditions may arise very different from those studied by us which would render its use more of a hazard than would appear to be the case from this investigation. Longer experience may show that even such slight storage of lead as was observed in these studies may lead eventually in susceptible individuals to recognizable lead poisoning or to chronic degenerative diseases of a less obvious character. In view of such possibilities the committee feels that the investigation begun under their direction must not be allowed to lapse. The respective States would be dependent upon the findings of such investigations for changes in their regulations. With the experience obtained and the exact methods now available, it should be possible to follow closely the outcome of a more extended use of this fuel and to determine whether or not it may constitute a menace to the health of the general public after prolonged use or under conditions not now foreseen.

Outside the question of ethyl gasoline it would seem from this investiga-

tion that wherever automobiles are housed together, there is an accumulation of lead dust which may prove to be a source of danger to the workers involved, in addition to the hazards arising from the production of carbon monoxide gas. The vast increase in the number of automobiles throughout the country makes the study of all such questions a matter of real importance from the standpoint of public health, and the committee urges strongly that a suitable appropriation be requested from Congress for the continuance of these investigations under the supervision of the Surgeon General of the Public Health Service, and for a study of related problems connected with the use of motor fuels.

W. H. Howell, *Chairman*
A. J. Chesley
David L. Edsall
Reid Hunt
W. S. Leathers
Julius Stieglitz
C.-E. A. Winslow

ANNOUNCEMENT OF MEETING OF THE AMERICAN ASSOCIATION OF INDUSTRIAL PHYSICIANS AND SURGEONS

The Eleventh Annual Meeting of the Association of Industrial Physicians and Surgeons will be held in Philadelphia, May 24 to 26, 1926.

Two amendments to the Constitution are proposed for adoption as follows:

1. That the fiscal year of the Association be changed from May to January 1.

2. That the Board of Directors be empowered to elect applicants to membership in place of such election by the Association.

An interesting and worth while program has been arranged by the committee and all members and interested friends are urged to attend. This program was printed in full in the April issue of THIS JOURNAL, pages 209 and 210.

Further details will be sent you from the secretary's office.

F. L. RECTOR
Secretary-Treasurer